

CA1 EP 50085152

Canada. EPS.

INVESTIGATION OF ENVIRONMENTAL EFFECTS OF HEAVY METAL
EMISSIONS FROM NON-FERROUS SMELTERS. / FENCO Engineers
Inc. 1985.

CA 1 EP50085152

ENVIRONMENTAL EFFECTS
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FROM NON-FERROUS SMELTERS



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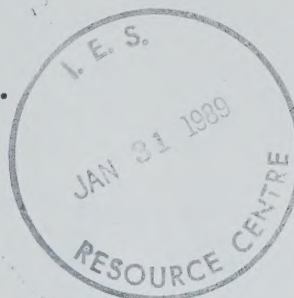
INVESTIGATION OF ENVIRONMENTAL EFFECTS
OF HEAVY METAL EMISSIONS
FROM NON-FERROUS SMELTERS

BY

FENCO Engineers Inc.

FOR

Environmental Protection Service
Environment Canada



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ABSTRACT

Particulate emission data pertaining to eight principal non-ferrous smelting operations in Canada are analysed. The report describes smelting operations relating to particulate emissions, reviews the dispersion and environmental effects of these emissions and discusses information gaps.

Available data varies markedly from smelter to smelter. Although reports of negative environmental impacts are reported in the locality of some smelters, the exact influence of heavy metals is difficult to assess.

1.0 SUMMARY

The Federal Department of Supply and Services contracted Fenco Engineers Inc. to complete a study of the environmental effects of heavy metals from Canadian non-ferrous smelters. Three tasks formed the basis of the project: an overview of smelting operations relating to heavy metal emissions, a summary of heavy metal distribution behaviour and related environmental or health effects, and the identification of information gaps. Smelting operations reviewed are: Inco at Sudbury and Thompson, Falconbridge at Sudbury, Hudson Bay Mining and Smelting at Flin Flon, Cominco at Trail, Noranda-Horne, Noranda-Gaspé, and Brunswick Smelting at Belledune.

Technical information surveys were made of operating companies, government agencies, commercial technical literature computer data bases, in-house files, and various conventional libraries.

The smelters operate tall stacks which are the principal sources of heavy metal emissions. Total calculated particulate emissions from these stacks for a 365 day period are compared in Figure S1. Fugitive emissions escaping the plants at low levels are generally not well identified. Inco-Sudbury is an exception; fugitives in this case are less than 5 percent of the total particulate emissions. Heavy metals emitted from the smelters are summarized in Table S-1. These are the most recent and complete data reported and in some cases reflect different operating periods from those outlined in Figure S-1. Particulate emission reductions are generally evident over the last decade due to a variety of programs and goals.

Gas cleaning is approached conventionally in the operations reviewed. Last line-of-defence particulate control is based on the use of electrostatic precipitators, scrubbers or baghouses, or a combination of these. Particulate removal, from smelter gases being treated for liquid SO₂ or sulphuric acid production, is even more complete and tail gases from these operations are relatively clean.

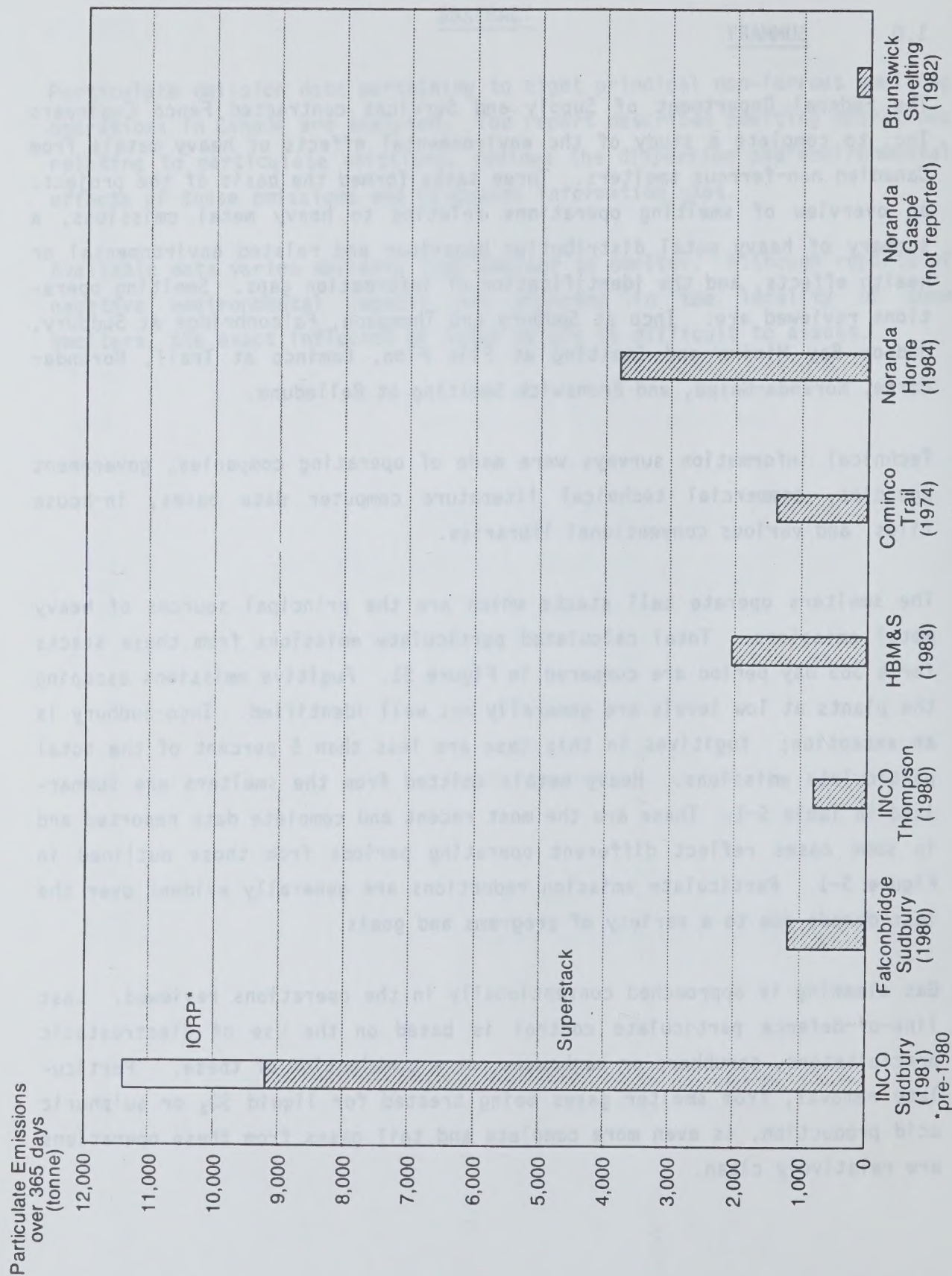


Figure S-1

Smelter Stack Emissions - Total Particulate

TABLE S-1
SUMMARY OF PARTICULATE AND HEAVY METAL EMISSIONS

tonnes per 365 days**

Smelter	Particulate*	Pb	Zn	As	HgΔ	Cd	Ni	Cu	Se	Fe	Co
Inco Sudbury (1973 to 81)	14,383	191	61	118	-	18	485	658	44	1703	
Falconbridge (1979)	865	13.4	2.9	6.4	-	2.2	9.6	11	-	98	
Inco - Thompson (1980)	730	1	1	3	-	0.1	42	6	0.1	164	1
Hudson Bay Mining & Smelting - Flin Flon (1982)	4,470***	330	995	125	-	45	3.5	103	-	119	-
Cominco - Trail (1974)	1,278	176	61	184	-	20.9					
Noranda - Horne (1984)	3,804	1107									
Noranda - Gaspé (1983)	-	86.9									
Brunswick Smelting - Belledune (1982)	101.5	47.5	3.1			3.7					

* includes fumes and vapours like mercury and arsenic

** available data calculated for a 365 day period

*** 1983 data is incomplete but a total particulate of 2150 tonnes is reported

Δ data not available

The heavy metal content of smelter particulate emissions generally reflects the types of metals being recovered. Concentrate impurity metals, especially species with a fume-like behaviour (arsenic) or a relatively high vapour pressure (mercury), typically concentrate in particulate emissions.

Smelter operations in Canada are affected by a variety of air quality regulations. Provincial emission control regulations range from specific stack emission limits and sampling programs to ground level concentration controls. Some smelters have developed SO₂ monitoring networks which are used to modify operations to meet ground level concentration limits. This control method likely reduces the local impact of particulate emissions since a correlation between SO₂ and particulate emissions has been identified for some smelters.

The quantity of available ambient air quality and dispersion data for each of the smelters varied considerably. While extensive sets of both raw and summarized data describe the effects of Inco and Falconbridge emissions on air quality in the Sudbury area, no data were available for Noranda's Murdochville smelter. In general, the available data were not recent. As discussed in the report, operators of some smelters have accumulated air quality survey data in unpublished form.

The types of dispersion data available for each smelter also varied. Data on the chemistry of particulate fallout during periods of precipitation were available only from the Sudbury area. Dry deposition rates were measured using dustfall jars at three smelters and by modelling from ambient air data at Sudbury. Estimates of total deposition rates (by snow sampling and/or moss traps) were available from three smelters. Ambient air data, including heavy metals, were also available from three smelters. Information on long-range transport of heavy metals was generally unavailable.

Human health problems related to exposure to heavy metals such as mercury, lead and cadmium have been reported world-wide. The impacts of non-ferrous

smelter emissions on human health are a function of exposure levels, the population profile (including age, sex and individual sensitivities) and the various activities of the population (including occupational exposures), making assessment of effects related to a specific site a very complex undertaking.

Although those heavy metal emissions suspected of highest toxicity potential were reviewed in this study, both data gaps and a lack of understanding of all adverse health effects present a serious limit regarding interpretation.

Populations are commonly exposed to multiple chemical agents on the job and in the community. The health effects of these agents in complex combinations cannot, in general, be assessed. It is known that some chemicals create a greater effect in combination than acting alone (synergism), and some act in the opposite manner (antagonism).

For example, the combination effect of sulphur dioxide, suspended particulate matter, nitrogen oxides, polynuclear aromatic hydrocarbons, etc., is not clearly understood, but attempts have been made to determine the impact on populations. In a Rouyn-Noranda mortality study, emissions of cadmium, lead, zinc and SO₂ were reported as contributing factors to lung cancers, but this conclusion has also been refuted.

It is also reported that adverse health effects from major air pollution sources are related to the distance from that source. In the Rouyn-Noranda study, the health effects of cadmium and arsenic were determined to be worst in populations living closest to the smelter.

The main limitations encountered in the health effects review were the scarcity of ambient air monitoring data and epidemiological data. Of the eight smelters, only Noranda (Horne) and Noranda (Murdochville) had any information directly relating to human health effects.

The effects of smelter emissions on the natural environment, resulting from atmospheric deposition of heavy metals, vary according to the composition of the concentrates, the processing and pollution control equipment, and the stack height. Available data are highly variable, in terms of both quantity and quality. However, despite these differences, some patterns are apparent, as follows:

- (i) Soils have been heavily contaminated by two or more metals in the vicinity of each of the smelters (within 3 km). Heavily contaminated soils have been shown to be toxic to plants, wherever this has been examined. In some cases, these concentrations could represent real or potential health hazards if affected plant species are eaten regularly (e.g. mercury in blueberries at Flin Flon, lead in forage at Trail). Data on metals in locally grown foods (for humans or domestic animals) however are lacking or very limited.
- (ii) The few wildlife studies which have been done do not provide sufficient data to accurately assess the impact of smelters on wildlife populations. However the effects which have been noted (some accumulation of metals in body tissues; apparent physiological stress as indicated by haemoglobin levels in mice; apparent shift in relative abundance of small mammals) appear to be minor compared to effects on vegetation, soils and the aquatic environment.
- (iii) Effects of air emissions on the aquatic environment have only been studied in some detail in the Sudbury area (Inco and Falconbridge), at Flin Flon and to a lesser extent at Noranda-Horne. In these cases, high concentrations of one or more metals have been found in surface water, sediments, plankton, macrophytes and fish. Some lake waters in the vicinity of the smelters have been shown to have toxic effects on fish and plankton due to heavy metal

contamination. Both lethal and sublethal effects have been reported. Concentrations of heavy metals in fish flesh have only been determined in the vicinity of one smelter (Noranda-Horne), where it was found that mercury levels were frequently greater than the acceptable limit for human consumption.

As a result of the above it is recommended that the following measures be taken to reduce the contamination of the environment:

1. The use of leaded gasoline should be discontinued.

2. The use of leaded gasoline should be discontinued.

3. The use of leaded gasoline should be discontinued.

4. The use of leaded gasoline should be discontinued.

5. The use of leaded gasoline should be discontinued.

6. The use of leaded gasoline should be discontinued.

* The heavy metals discussed in the report are lead, cadmium, mercury, chromium, nickel, copper, zinc, and manganese.

2.0 INTRODUCTION

2.1 Project Background

Fenco Engineers was commissioned by the Federal Department of Supply and Services to carry out a study of the environmental effects of heavy metal emissions* from Canadian non-ferrous smelters. The contract number was 52SS-KE14S-4-0271.

The investigation was organized into three tasks as follows:

- i. an overview of operations at eight major smelters including process descriptions, climatic settings, pollution abatement equipment, emission data, regulatory controls and monitoring programs as they apply to heavy metal emissions
- ii. an outline of deposition rates, ambient concentrations, long range transport, and observed environmental or health effects related to the metal emissions
- iii. identification of information gaps.

This report contains the results of the literature searches, interviews, report reviews, and data analyses dealing with the tasks outlined above.

2.2 Information Retrieval

Information sources surveyed for this project were the following:

- i. smelter operators and associated environmental control departments

* The heavy metals discussed in the report are lead, zinc, arsenic, mercury, cadmium, nickel, copper, selenium, and cobalt.

- ii. provincial government environment ministries
- iii. numerous computer accessed technical data bases such as environmental bibliography, compendex, enviroline, and pollution abstracts
- iv. the federal Environmental Protection Service literature files
- v. in-house technical files

Reports identified in the various data bases explored were obtained from the most accessible library or file source.

Most of the information reviewed in this study is in the public domain. Surveys of operating companies for emission monitoring and control methodologies were also conducted with their co-operation.

2.3 Acknowledgements

Fenco gratefully acknowledges the co-operation and assistance of the operating companies, government agencies, and libraries contacted during the course of the study. Environment Canada contacts were Dr. L. Buffa, C. Jose and W.B. Blakeman.

3.0 SMELTING OPERATIONS OVERVIEW

3.1 Summary of Operations

The following plant descriptions illustrate the means by which heavy metal emissions are produced during the processing of metal concentrates. Non-ferrous metal values typically occur as sulphide minerals which are mined unavoidably with surrounding rock and together form ores. Within the principal sulphides, various impurity base metals and precious metals are found which to a large extent characterize a deposit.

Metallurgical processing of ore to metal consists generally of the following approach:

- i. Separating sulphides from rock to form a concentrate or a number of concentrates. The techniques include comminution, flotation, magnetic separation, and gravity separation.
- ii. Roasting and/or smelting the concentrates to remove most of the sulphur and iron (which are the other principal constituents in sulphide minerals). Some of the impurity metals are rejected at this stage.
- iii. Refining the crude metals further in pyrometallurgical or hydrometallurgical operations to yield commercial metal products. The balance of the impurity elements are rejected during refining. Precious metals are usually recovered in a crude form as a residue from refining operations.

Particulate entrained in metallurgical process gas streams generally reflect the composition of the concentrates and fluxes being processed and their behaviour in the metallurgical processing system. Stack emissions, on the other hand, reflect both the process dust make and the dust collection success. Principal process gas streams, from steps ii and iii above,

above, cleaned to various degrees, typically vent from tall stacks which are the major sources of particulate. Low level stacks and roof vents or monitors discharge building air which clears the workplace of fugitive emissions. Fugitive emissions also escape from exposed concentrate storage areas and handling facilities.

Particulate emissions reviewed herein are for 365 days based on stack sampling data. This accounting technique indicates the relative magnitude of the emissions and is a simple means of comparing the eight smelters. Arsenic and mercury are reported as particulate although a fume or vapour may more accurately describe these elements due to their chemical behaviour.

The eight smelters described are:-

Inco - Sudbury

Inco - Thompson

Falconbridge - Sudbury

Hudson Bay Mining and Smelting - Flin Flon

Cominco - Trail

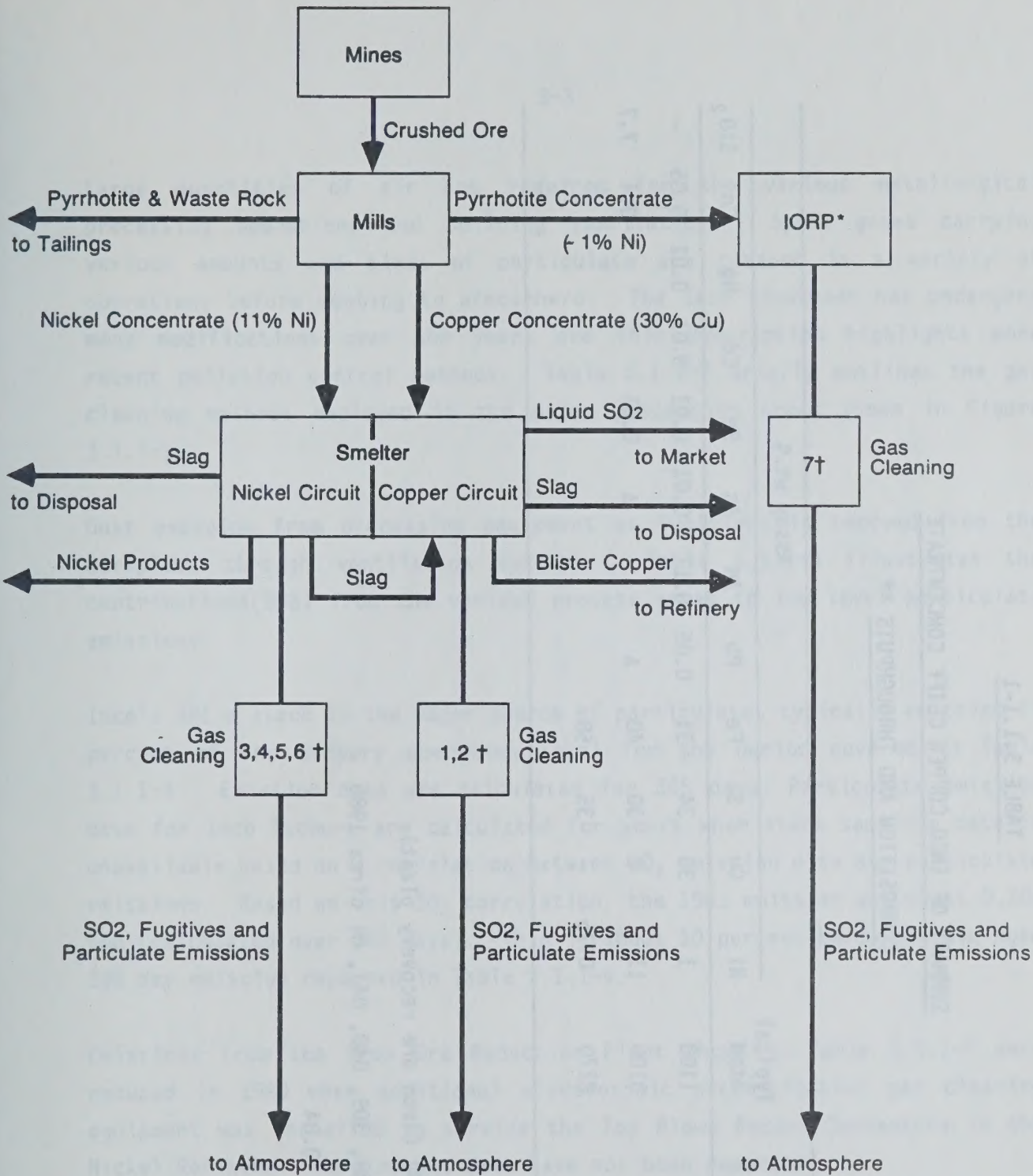
Noranda - Horne

Noranda - Murdochville

Brunswick Smelting - Belledune

3.1.1 Inco - Sudbury

Inco-Sudbury is fully integrated, processing ore to refined metals. Figure A II-1 in Appendix II outlines the complexity of the circa 1984 flowsheet. A simplified block diagram is shown in Figure 3.1.1-1. Inco's concentrators produce three concentrates described in Table 3.1.1-1. Sudbury concentrates are considered relatively free of base metal "impurities".



* Iron Ore Recovery Plant

† Gas Cleaning Methods as Outlined in Table 3.1.1-2

Figure 3.1.1-1

INCO Operations at Sudbury

TABLE 3.1.1-1

SUMMARY OF INCO COPPER CLIFF CONCENTRATE

COMPOSITION AND THROUGHPUTS **

Concentrate	Typical mtpd	Assay wt. %										
		Ni	Cu	S	Fe	Pb	Zn	As	Se	Cd	Hg	Co
Copper Circuit	1100	1	30	34	31	0.05	0.17	0.01	0.01	0.01	0.01	0.05
Nickel Circuit	3100	11	2	30	40	Λ		Λ	0.01			0.4
Pyrrhotite *	2270	0.75	-	35	58							-

* feed for IORP (iron ore recovery plant)

** Reference 038, 309, 040, 041, 01 circa 1980

Λ wt% Pb + As 0.04

Large quantities of air are required for the various metallurgical processing operations and building ventilation. Spent gases carrying various amounts and kinds of particulate are cleaned in a variety of operations before venting to atmosphere. The Inco flowsheet has undergone many modifications over the years and this description highlights more recent pollution control methods. Table 3.1.1-2 briefly outlines the gas cleaning methods employed in the major processing areas shown in Figure 3.1.1-1.

Dust escaping from processing equipment as fugitives is removed from the workplace through ventilation systems. Table 3.1.1-3 illustrates the contributions(038) from the various process areas to low level particulate emissions.

Inco's 381 m stack is the major source of particulate, typically emitting 75 percent of the Sudbury operation total for the period covered in Table 3.1.1-4. Emission data are calculated for 365 days. Particulate emission data for Inco Sudbury are calculated for years when stack sampling data is unavailable based on a correlation between SO_2 emission data and particulate emissions. Based on this SO_2 correlation, the 1981 emission was about 9,200 tpa (calculated over 365 days). This is about 10 percent below the averaged 365 day emission reported in Table 3.1.1-4.

Emissions from the Iron Ore Reduction Plant shown in Table 3.1.1-4 were reduced in 1980 when additional electrostatic precipitation gas cleaning equipment was installed to service the Top Blown Rotary Converters in the Nickel Refinery. More recent data have not been reported.

TABLE 3.1.1-2

SUMMARY OF POLLUTION CONTROL EQUIPMENT SERVICING

THE COPPER CLIFF SMELTER PROCESS AREAS *

Process Area	Stack Used	Air Pollution Control Equipment	Ref. Key Figure 3.1.1-2
Copper Flash Furnace	381 m	baghouse (concentrate dryer), venturi scrubbers, wet precipitator, Cotrell #3, (liquid SO ₂)	1
Copper Converters	381 m	electrostatic precipitators (#3)	2
Nickel Roasters/Reverb. Furnaces	381 m	electrostatic precipitator (#1 & #4)	3
Nickel Converters	381 m	electrostatic precipitators (#2, #5)	4
Matte Processing Fluid Bed Roasters	381 m	electrostatic precipitator (#3)	5
Nickel Refinery (TBRC's)	194 m	electrostatic precipitators	6
Iron Ore Recovery Plant	194 m	electrostatic precipitators, sulphuric acid production	7

* excludes coarse particle removal such as settling chambers, balloon flues, cyclones; references 040, 037, 013, 016

TABLE 3.1.1-3

RELATIVE PROCESS CONTRIBUTIONS*
TO LOW LEVEL (FUGITIVE) EMISSIONS FROM
THE COPPER CLIFF SMELTER

<u>Process Source</u>	<u>% Particulate Contribution</u>
Copper Converters	70
Copper Flash Furnace	3
Nickel Reverberatory Furnace Circuit	9
Nickel Converters	9
Others	<u>9</u>
Total	100

* Reference 01

TABLE 3.1.1-4

AVERAGE YEARLY (365 DAY) EMISSIONS* (TONNES) OF MAJOR POLLUTANTS IN THE
SUDBURY BASIN FROM INCO FOR THE PERIOD 1973 TO 1981

	T O N N E S									
	Total Particulate	Iron	Copper	Nickel	Zinc	Lead	Selen- ium	Arsenic	Cadmium	Mercury
381 Meter Smelter Stack **	11,417	990	245	228	61	184	44	114	18	-
194 Meter IORP Stack +	2,380	643	171	226		6		4		-
Copper Cliff Smelter (Low Level)o	586	70	242	31		0.6		0.1		-
Total	14,383	1,703	658	485	61	190.6	44	118.1	18	-

* Reference 01 summarizes testwork results in references 016, 013 and various Inco Process Technology memos.

** Emissions of total particulate, iron, copper and nickel were calculated from correlations with SO₂ emissions.

+ The total particulate and trace metal emission rates were calculated from stack measurements performed in 1977.

o Emission rates for all substances determined from measurements conducted in 1978 and 1979 and prorated to other years on the basis of production.

3.1.2 Falconbridge - Sudbury

Falconbridge Ltd. principally smelts concentrates from the Sudbury area. The smelter is located next to the townsite of Falconbridge about 20 km northeast of the city of Sudbury. Figure A II-2 in Appendix II shows the current roasting and electric furnace smelting process. Figure 3.1.2-1 outlines a simplified block diagram. Peirce-Smith converting produces nickel-copper matte which is refined in Norway.

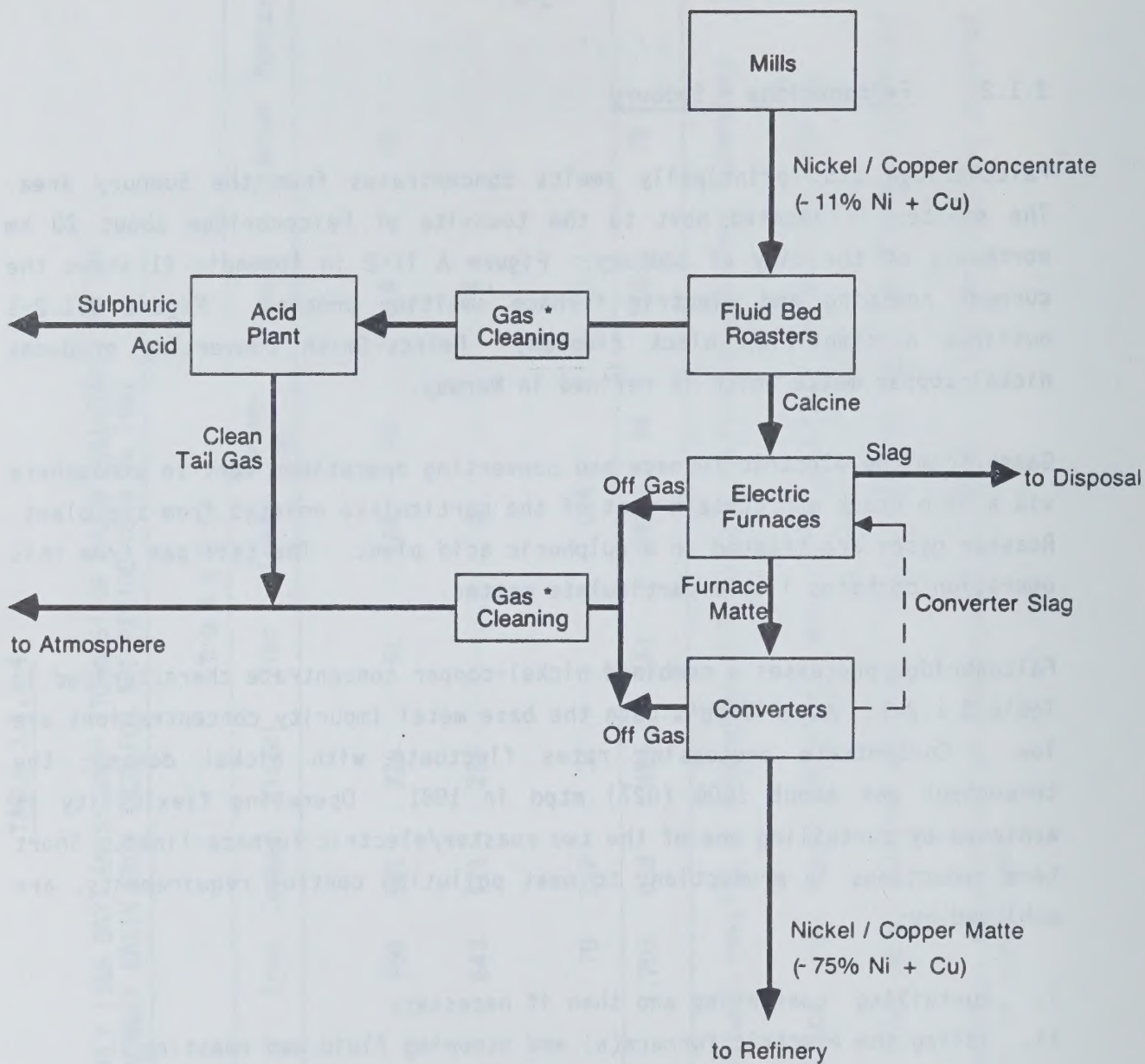
Gases from the electric furnace and converting operations vent to atmosphere via a 93 m stack and contain most of the particulate emitted from the plant. Roaster gases are treated in a sulphuric acid plant. The tail gas from this operation contains little particulate matter.

Falconbridge processes a combined nickel-copper concentrate characterized in Table 3.1.2-1. As in Inco's case the base metal impurity concentrations are low. Concentrate processing rates fluctuate with nickel demand; the throughput was about 1800 (027) mtpd in 1981. Operating flexibility is achieved by curtailing one of the two roaster/electric furnace lines. Short term reductions in production, to meet pollution control requirements, are achieved by:

- i. curtailing converting and then if necessary
- ii. idling the electric furnace(s) and stopping fluid bed roasting

All three units can resume operation relatively quickly.

Table 3.1.2-2 outlines the pollution control equipment operated by Falconbridge and referenced in Figure 3.1.2-2. Construction of an acid plant and new smelter in 1978, reduced emissions significantly.



* See Table 3.1.2-2 for equipment details

Figure 3.1.2-1

Falconbridge Smelter Process Diagram

TABLE 3.1.2-1

**FALCONBRIDGE NICKEL COPPER
CONCENTRATE COMPOSITIONS* 1981**

<u>Nickel-Copper Concentrate</u>	<u>Ni</u>	<u>Cu</u>	<u>Co</u>	<u>S</u>	<u>Fe</u>	<u>SiO₂</u>	<u>Other gangue & metals</u>
Falconbridge Mill	6.45	4.64	0.29	31.9	42.6	6.09	8.0
Strathcona Mill	6.20	5.18	0.25	30.8	41.4	7.1	9.07

TABLE 3.1.2-2

**POLLUTION CONTROL EQUIPMENT
OPERATED AT THE FALCONBRIDGE SMELTER**

<u>Production Area</u>	<u>Control Equipment **</u>
Fluid Bed Roasters	- Electrostatic Precipitators - Sulphur Acid Production including gas scrubbing and mist precipitators
Electric Furnaces and Peirce Smith Converters	- Electrostatic Precipitator

* Reference 027

** Coarse particle removal in cyclones and settling chambers are not included.

TABLE 3.1.2-3

**ESTIMATE OF PARTICULATE EMITTED
FROM THE 93 m FALCONBRIDGE STACK
(Based on 365 days/year)**

Year	Particulate tonne										Reference
	Total	Fe	Ni	Cu	Pb	As	Zn	Se	Hg	Cd	
1979	865	98	9.6	11	13.4	6.4	2.9	-	-	2.2	01
1980	1204	211	18.6	25.5	26.3						027
1974*	5694	1752	332	252	65.7						027

* combined sinter plant and smelter stack emissions - the sinter plant was shut down in 1978.

Table 3.1.2-3 shows the typical annual level of particulate emitted since 1978 when the current smelter commenced operation. Data on particulate fugitives are not available nor are there significant stack data for operations prior to 1978. Prior to installation of the new smelting process in 1978, particulate emissions were generally higher than current levels. Comparative particulate fugitive emission data for pre and post 1978 are also unavailable. Fugitives are mainly emitted from the Peirce-Smith converters.

3.1.3 Inco - Thompson

Although less complex than Inco's Sudbury operation, Inco - Thompson also processes ore to metal. Fig. 3.1.3-1 sketches (M13) the flowsheet which is conceptually similar to the Falconbridge operation described in Section 3.1.2. Electric furnace smelting and electrolytic refining of nickel were chosen mainly due to the availability of inexpensive electrical energy.

The smelter capacity is nominally 4600 mtpd of concentrate with 5 roaster/electric furnace couples operating. Concentrate smelted has a composition shown in Table 3.1.3-1. The nickel to copper ratio is greater in Thompson ores than those mined in Sudbury, permitting a simpler overall flowsheet.

Concentrates treated at Thompson are relatively free of other base metal impurities. The ratio of nickel to other elements in the stack emissions supports this.

The Thompson operation controls particulate emissions in a gas cleaning system using cyclones and electrostatic precipitators.

A common precipitator system removes particulate following which the combined process gases pass to atmosphere via a 152 meter stack. Inco Thompson does not operate a flue gas desulphurization system.

Particulate emissions from the Inco Thompson stack have decreased from levels of 30 mtpd in 1972 (M7) to about 2 mtpd in 1980. The reduction in particulate emissions is attributed to gas cleaning circuit control improvements.

Table 3.1.3-2 outlines particulate emissions(M14) in 1979 and 1980 and associated metal contents. Daily emissions were multiplied by 365 for an annual total for comparison with other operations. The principal metal is

ROASTING & SMELTING

CONVERTING / ANODE CASTING

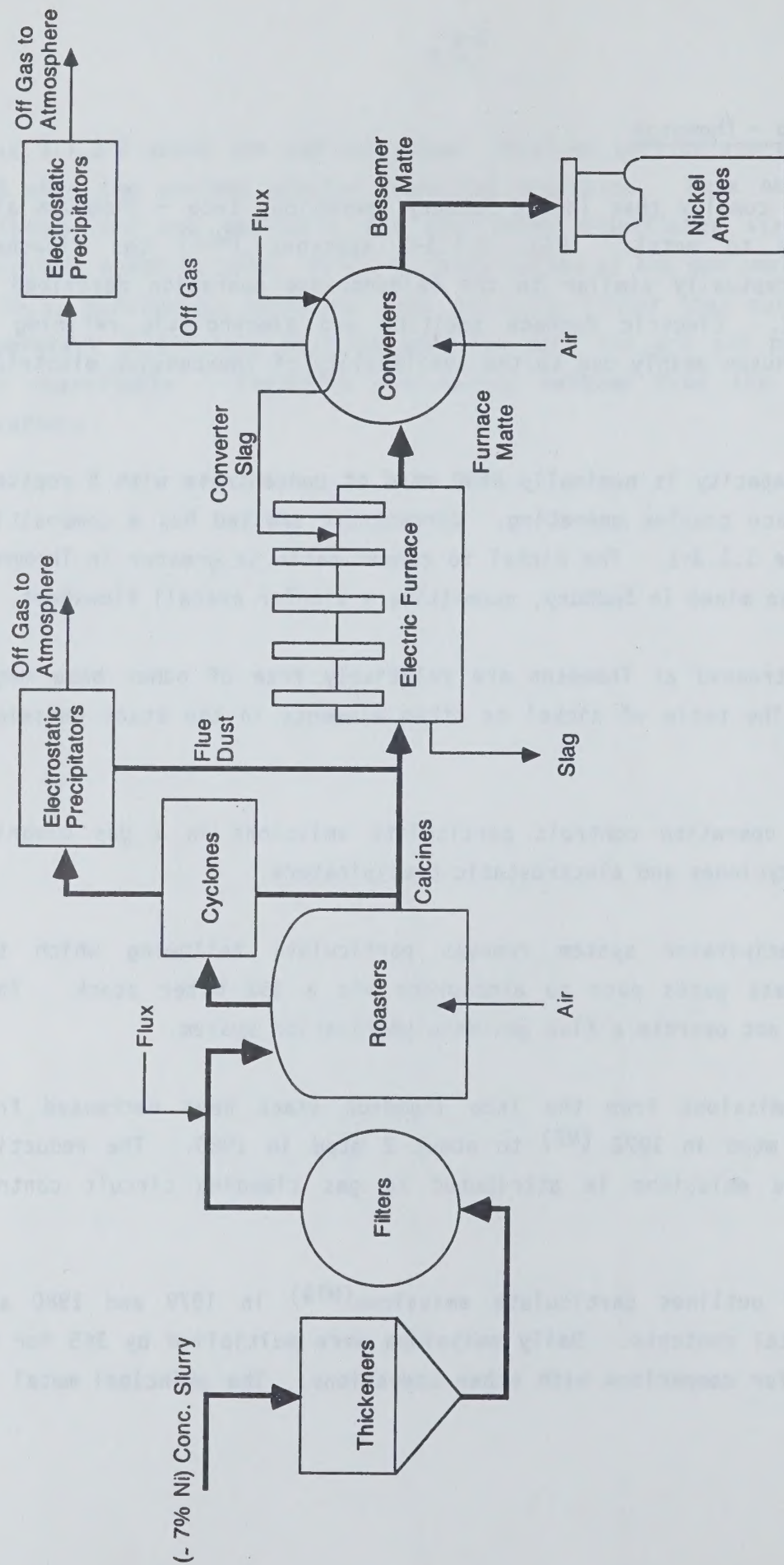


Figure 3.1.3-1

Flowsheet for the Thompson Smelter

TABLE-3.1.3-1

COMPOSITION OF CONCENTRATE TREATED AT
INCO THOMPSON

<u>Material</u>	<u>Assay wt %</u>				
	<u>Ni</u>	<u>Cu</u>	<u>S</u>	<u>Fe</u>	<u>Others</u>
Nickel Concentrate	7	0.3	27	41	24.8

TABLE 3.1.3-2

PARTICULATE EMISSIONS FROM INCO THOMPSON
152 M STACK (M14)
(Calculated for 365 days)

<u>Year</u>	<u>Tonnes</u>									
	<u>Total</u>	<u>Fe</u>	<u>Ni</u>	<u>Cu</u>	<u>Pb</u>	<u>Co</u>	<u>Zn</u>	<u>Cd</u>	<u>As</u>	<u>Se</u>
1979	839	178	45	7	2	1	5	0.2	2	0.2
1980	730	164	42	6	1	1	1	≤0.1	3	0.1

iron present at about four times the concentration of nickel. Base metal impurities other than copper are reported at concentrations 45 times less than nickel.

Data on low level particulate fugitives from the plant are unavailable. The main source of fugitive emissions are the Peirce-Smith converters.

3.1.4 Hudson Bay Mining and Smelting - Flin Flon

Custom and in-house concentrates at Hudson Bay Mining and Smelting (HBMS) are processed to lead concentrate, electrolytic zinc, electrolytic cadmium, and anode copper. A flowsheet (M18) for the 1983 operation, is shown in Figure 3.1.4-1. Concentrate throughputs and compositions for the HBMS operation are summarized in Table 3.1.4-1. Lead concentrate is shipped as a mill product, copper is extracted through pyrometallurgical processes, and zinc recovered through combined roasting, electrowinning and slag fuming processing. Typically the copper circuit produces about 190 mtpd of copper as metal and the zinc circuit 220 mtpd of zinc.

The copper and zinc circuit principal process areas are summarized in Table 3.1.4-2 showing the gas cleaning methods employed. Residual dust in process gases is vented to atmosphere via a 251 m stack.

Dust sampling in the main 251 m stack is carried out to comply with provincial regulatory requirements. Results from 1983 tests are shown in Table 3.1.4.3. The average 1983 daily particulate emission (M18) is about 6 mtpd. This is a significant reduction from daily emissions in 1981 (M1) when SO_2 emissions and hence production rates were apparently similar. Additional electrostatic precipitator capacity accounts for the improvement.

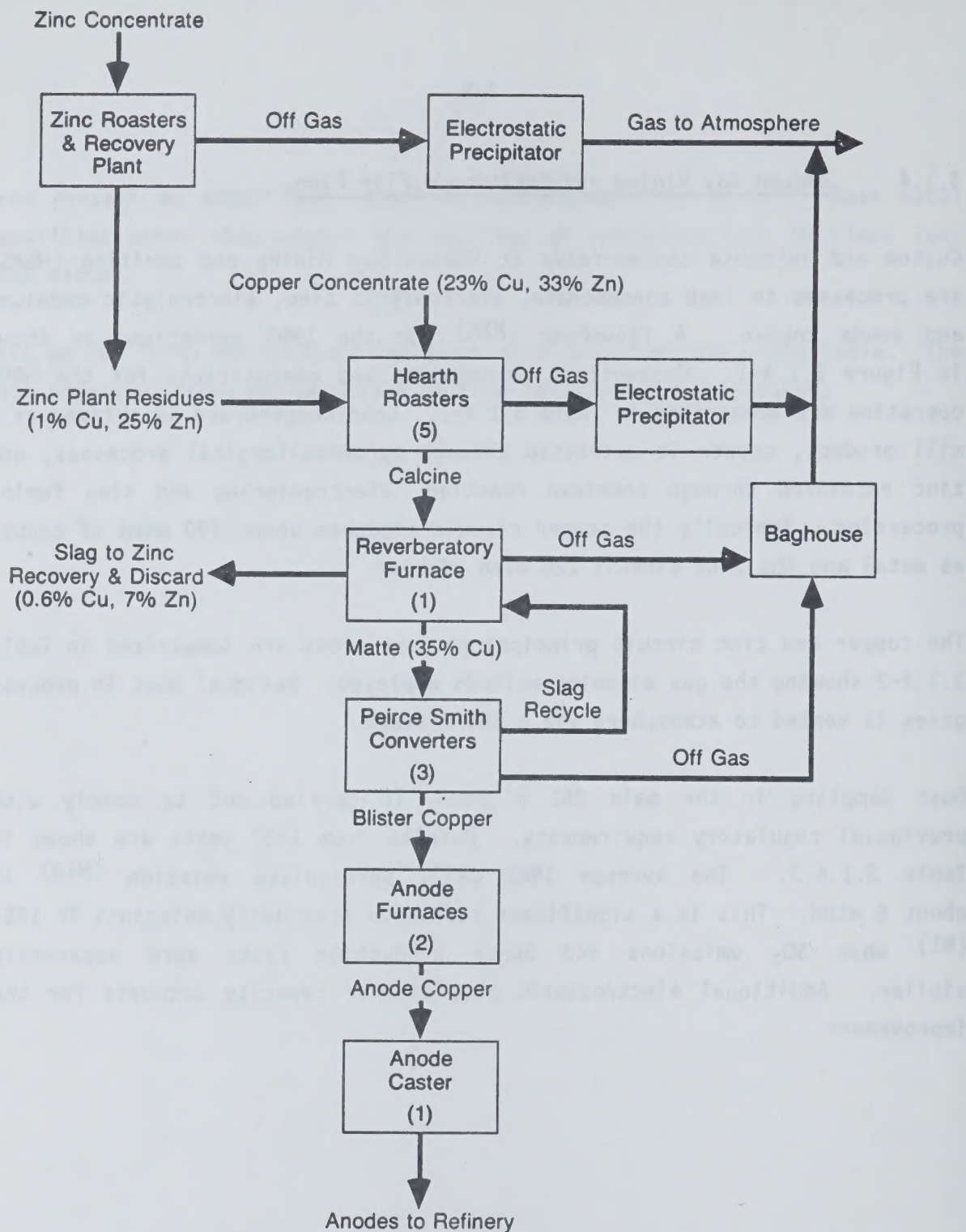


Figure 3.1.4-2

HBMS - Flin Flon Smelter Flowsheet

TABLE 3.1.4-1

SUMMARY OF CONCENTRATE PROCESSING
RATES AND COMPOSITIONS AT
HUDSON BAY MINING AND SMELTING

Concentrate	Typical mtpd	Assay Wt %				
		Cu	Pb	Zn	Fe	S
Copper	825	23		3	~30	30
Zinc	440(G7)	07		50		~30

TABLE 3.1.4-2

SUMMARY OF GAS CLEANING METHODS
USED IN THE VARIOUS PROCESS AREAS
AT HUDSON BAY MINING AND SMELTING

<u>Process Area</u>	<u>Pollution Control Equipment</u>
1. <u>Copper Circuit</u>	
Concentrate Dryer	Cyclones
Multi Hearth Roasters	Electrostatic Precipitator
Reverberatory Furnace	Waste Heat Boiler, Electrostatic* Precipitator, Baghouse
P.S. Converters	Electrostatic Precipitator* Baghouse
Anode Casting	None
2. <u>Zinc Circuit</u>	
Multihearth Roasters	Electrostatic Precipitators
Fuming Furnace	Cooling Tower & Baghouse
Zinc Casting	None

* common units

TABLE 3.1.4-3

PARTICULATE EMISSIONS FROM HUDSON BAY
MINING AND SMELTING 251 M STACK (M18)

Year	particulate* (tonnes per 365 days)								
	Total	Fe	Ni	Cu	Zn	As	Cd	Pb	Hg
1983	2,150								
1982	4,470	119.	3.5	103.	995.	125.	45.	330.	
1981	14,400	1290.	8.6	202.	6077.	84.	62.	563.	
1977						113.			11.5

* daily rate times 365 for comparison with other operations.

3.1.5 Cominco Trail

Cominco Trail operations are divided into two principal metallurgical treatment areas producing lead and zinc intermediates which are eventually refined to metals and various by-products. Sulphur is recovered in fertilizer and chemical production facilities.

A flowsheet (B12) describing the zinc operation is outlined in Fig. 3.1.5-1. Zinc roaster off-gas is cleaned and the sulphur recovered as sulphuric acid. As a result, the zinc operation emits only moderate amounts of particulate.

Lead production is outlined in Fig. 3.1.5.2. The smelter produces about 460 mtpd of bullion (B8) which is electrolytically refined and shipped as cast pigs. To achieve this, lead concentrates are agglomerated on a sinter strand, smelted in a blast furnace to bullion and then refined.

Concentrates processed at Trail are a blend of Sullivan, Pine Point and custom materials. An example of the concentrate feed is shown in Table 3.1.5-1.

Particulate emissions from the lead operations principally vent from the sinter plant stack, (120 m) blast furnace stack (55 m), and the refinery area packed bed scrubber stack. Trail's pollution control permit lists stacks in the lead processing area with a daily total particulate emission limit of 5.3 tonnes. The lead content of particulate emissions shown in the permit totals 0.48 mtpd (B1,B2). Table 3.1.5-2A shows the total emissions from stacks sampled by Cominco in 1974. Since these measurements were made, Cominco has installed a scrubber in the lead refinery which has reduced particulate emissions as noted in Table 3.1.5-2B. The British Columbia Ministry of the Environment has also issued Variance Orders (B13,

FIGURE 3.1.5-1
COMINCO LTD., TRAIL
SIMPLIFIED FLOW DIAGRAM OF THE ZINC ROASTING
AND SULPHUR DIOXIDE RECOVERY PROCESSES

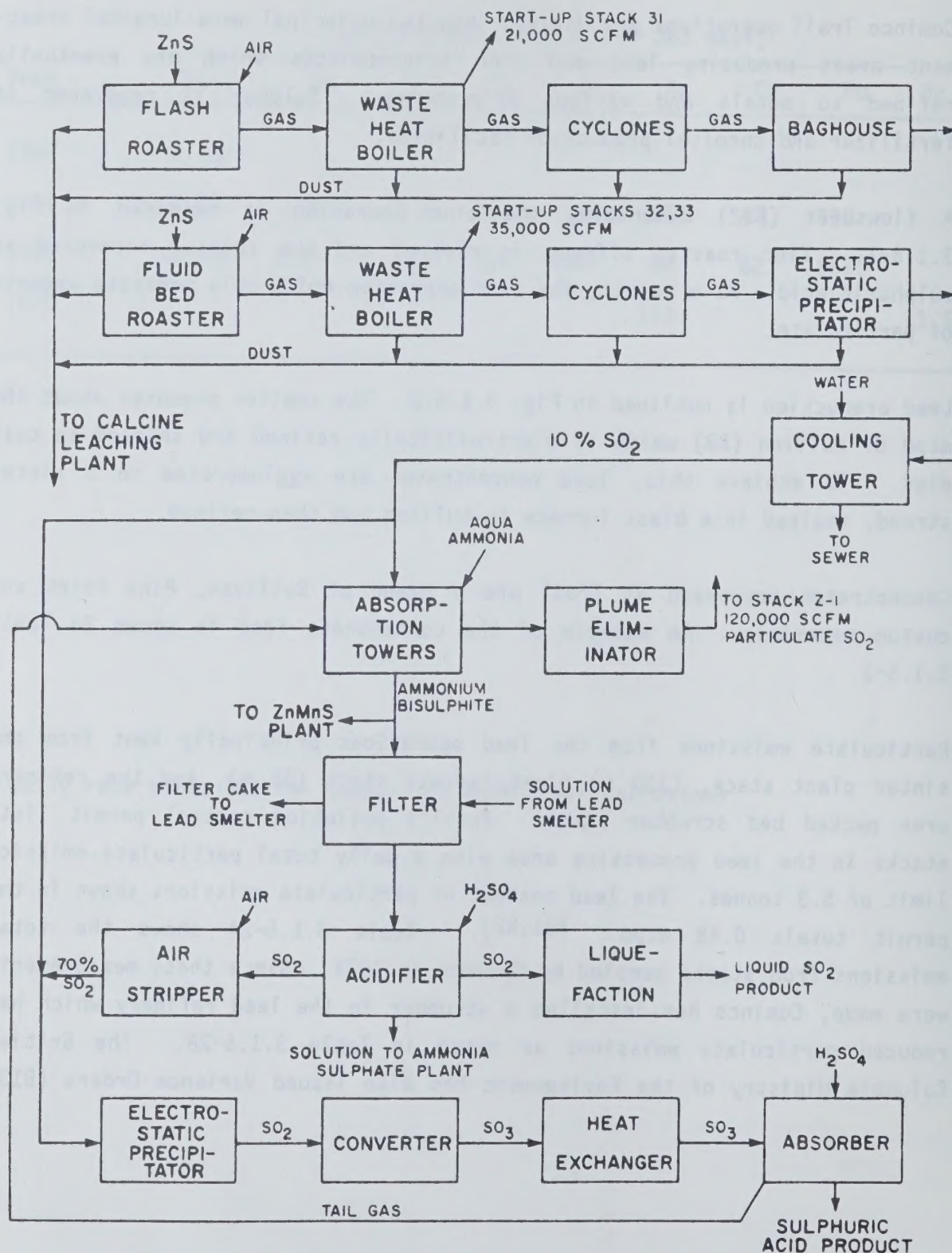
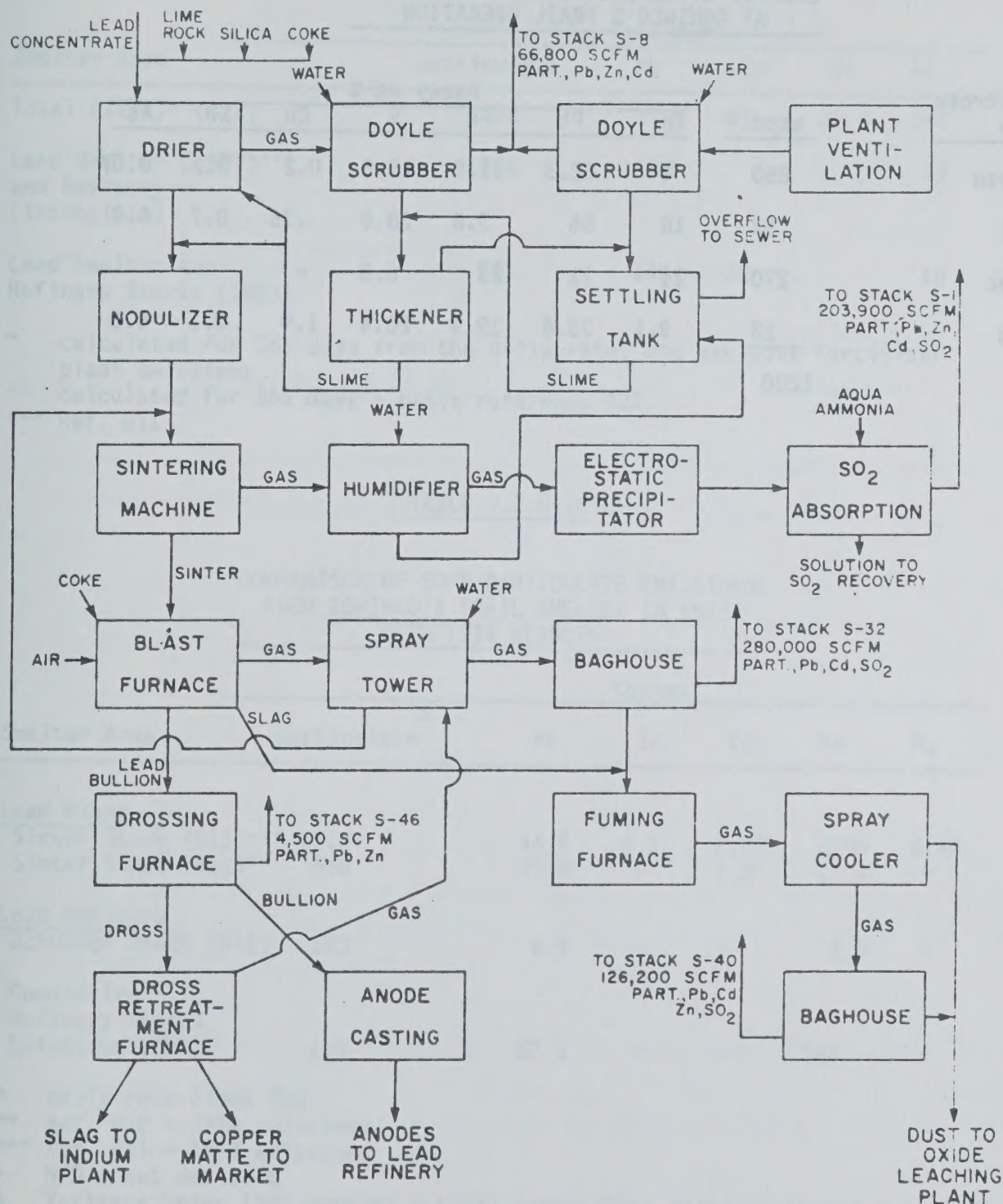


FIGURE 3.1.5-2
COMINCO LTD., TRAIL
SIMPLIFIED FLOW DIAGRAM OF THE
LEAD SINTERING AND SMELTING PROCESSES



Note: PART. = PARTICULATE

TABLE 3.1.5-1

EXAMPLE OF LEAD CONCENTRATES TREATED
AT COMINCO'S TRAIL OPERATION

Concentrate Type	mtpd	Assay wt %						
		Zn	Pb	Fe	S	Cu	Sb	As
Sullivan	850	4	62.5	11.5	18.6	0.2	0.2	0.07
Tatasi	52	16	55	3.8	18.8	.35	0.7	0.2
Tadanac	270	21	11	23	6.8	-	-	-
Others	<u>28</u>	9.1	33.6	19.9	20.4	1.9	0.1	0.5
Total	1200							

TABLE 3.1.5-2A

SUMMARY OF PARTICULATE EMISSIONS
FROM COMINCO'S TRAIL SMELTER

Smelter Area	tonnes*				
	particulate	Pb	Zn	Cd	As
Total (1974)* (B12)	1278	176	61	20.9	184
Lead Smelter (1979)*** and Refinery (incomplete)	1235	133			53
Lead Smelter and Refinery Stacks (1983)	981	148	38		18

* calculated for 365 days from the daily rate, and excludes fertilizer plant emissions

** calculated for 365 days - basis reference B23

*** Ref. B11

TABLE 3.1.5-2B

COMPARISON OF SOME PARTICULATE EMISSIONS
FROM COMINCO'S TRAIL SMELTER IN 1979
WITH 1974 RESULTS

Smelter Area	tonnes*					
	^Δ particulate	Pb	Zn	Cd	As	Hg
<u>Lead Plant</u>						
Sinter Stack (B11)***	1113.	44.6	4.7	2.27	N/D+	0.44
Sinter Stack (B12)**	538	53.8	-	7.3	14.4	-
<u>Lead Refinery</u>						
Scrubber Stack (B11)	123	8.6	-	-	5.3	-
Cumulative Refinery Stacks Emissions (B12)	195	57.1	-	-	167	-

* daily rate times 365

** Ref. B12 - 1974 emissions

*** Ref. B11 - 1979 emissions

+ N/D = not detected

Δ Variance Order 1983 permits a total particulate increase from 0.1 to 0.25 GR/SCF and a lead increase from 0.005 to 0.02 GR/SCF.

TABLE 3.1.5-3

SUMMARY OF POLLUTION CONTROL EQUIPMENT
ON PRINCIPLE UNIT OPERATIONS AT COMINCO TRAIL

	<u>Process Area</u>	<u>Pollution Control Equipment</u>
1.	<u>Zinc Plant</u>	
	Roasters	cyclones electrostatic precipitator scrubber, sulphuric acid plant
2.	<u>Lead Smelter</u>	
	Sinter Machine	scrubber, electrostatic precipitator
	Blast Furnace	scrubber, bag house
	Zinc Fuming Furnace	cooler, baghouse

14, 15, 16) which alter permissible emissions from a number of stacks. The most notable change is the increase in sinter stack allowable emission rate noted in Table 3.1.5-2B. Testing carried out by the EPS (B11) in 1979 showed an increase in particulate from the sinter plant stack compared to the 1974 results which is consistent with the Variance Orders. Fugitive emissions have not been reported but can be expected from the lead blast furnace, zinc roasters, and lead sintering machine.

Gas cleaning methods used in the various plant operating areas are outlined in Table 3.1.5-3.

3.1.6 Noranda Horne Smelter

Noranda's Horne operation currently operates as a custom smelter treating copper concentrates containing a variety of impurities. (Q19)

Feed concentrates are smelted in a wet charge reverberatory furnace and a Noranda Reactor followed by conventional Peirce Smith converting. A simplified smelter flowsheet circa. 1983 is shown in Fig. 3.1.6-1. An example of concentrate and reverts smelted in the Noranda Reactor(Q18) is outlined in Table 3.1.6-2.

Concentrates bearing higher impurity concentrations are smelted in the reverberatory furnace to maintain the anode copper impurity specification. With oxygen enrichment, the Noranda Reactor processes 1880 mtpd of concentrate feeds while the reverberatory furnace throughput is 1050 mtpd using oxyfuel roof burners.(Q19)

Sulphur dioxide is not recovered from flue gases at the Horne. Process gases are cleaned(Q19) in a system of six electrostatic precipitators (ESP's) prior to venting to atmosphere as noted in Table 3.1.6-3.

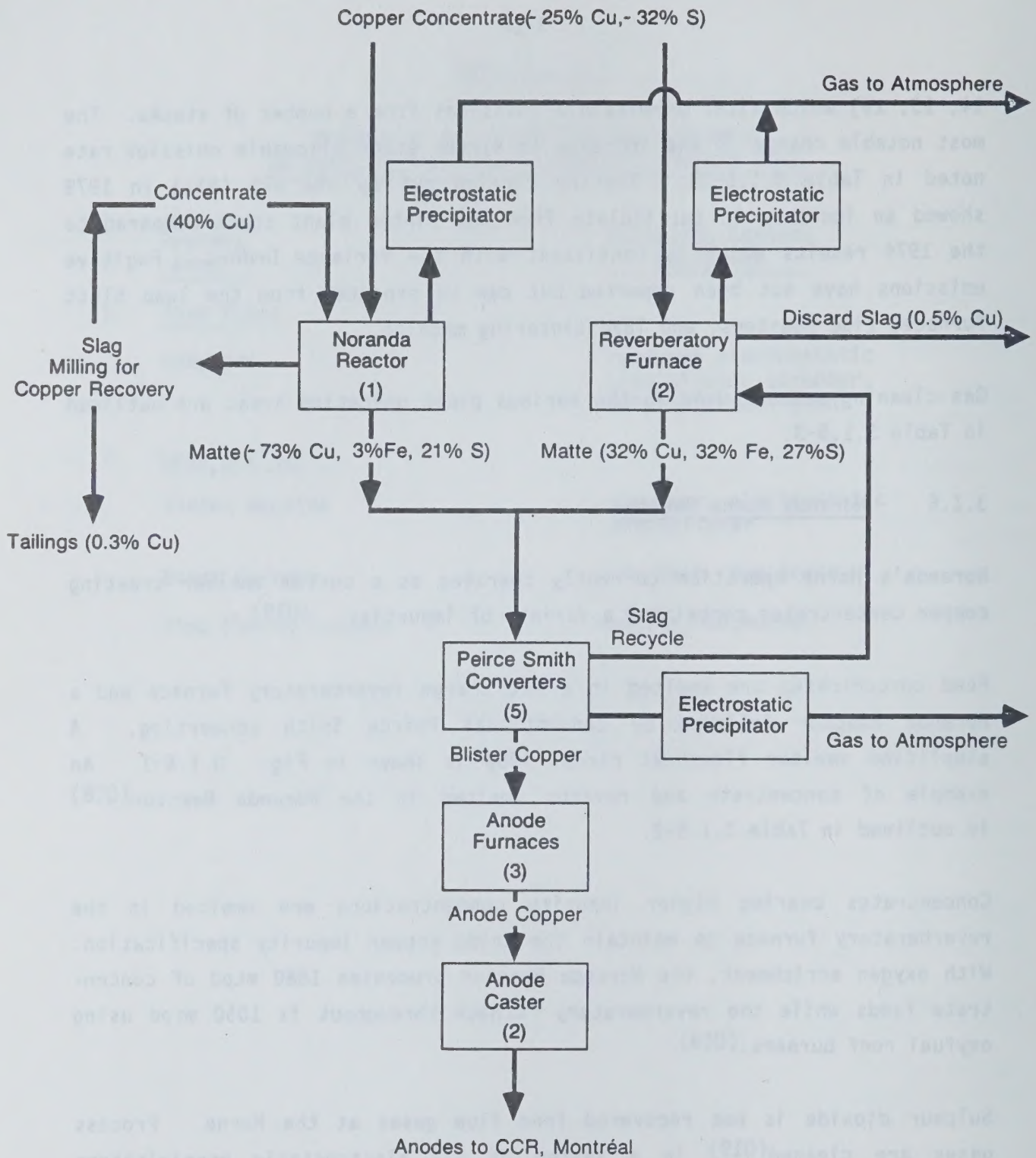


Figure 3.1.6-1

Horne Smelter Flowsheet

TABLE 3.1.6-2

EXAMPLE OF NORANDA REACTOR
FEED MATERIALS

<u>Material</u>	<u>Assay Wt. %</u>					
	<u>Cu</u>	<u>Fe</u>	<u>SiO₂</u>	<u>S</u>	<u>Pb</u>	<u>Zn</u>
Copper Concentrate	23.5	29.0	3.0	33	3.2	3.8
Purchased Reverts	29.5	22.5	16.2	13	0.1	0.4

TABLE 3.1.6-3

PROCESS GAS CLEANING
AT NORANDA'S HORNE SMELTER

<u>Operations Area</u>	<u>Gas Cleaning Equipment</u>
Reverberatory Furnace	2 Cottrells (ESP's)
Noranda Reactor	1 Cottrell (ESP)
Peirce-Smith Converters	3 Cottrells (ESP's)

TABLE 3.1.6-4

SUMMARY OF PARTICULATE EMISSIONS
FROM THE NORANDA HORNE SMELTER

<u>Process Area</u>	<u>tonnes per 365 days*</u>	
	<u>1978</u>	<u>1984</u>
Noranda Reactor	438	
Reverberatory Furnace	4950	
Converters	3066	
TOTAL	8454	3804**

* kg/hr x 24 x 365 for comparison with other operations (Q8, Q22)

** Lead emissions for the operating year were 1080 tonnes from the stacks and 27 tonnes as fugitives (Q23)

Dust in gases exhausting from the two active stacks is sampled continuously on a 24 hour basis. A third sampler collects particulate from the Noranda Reactor gas cleaning system which allows contributions from the various process sources to be identified. This system is discussed further in Section 3.3. Particulate emissions(Q8) from the three main process areas during 1977 are summarized in Table 3.1.6-4. Analytical data are not available. Emissions in 1982 were expected to be 21 percent of those reported for 1978 due to the elimination of roasters, a reverberatory furnace and the installation of Waffle hoods on their Peirce-Smith converters. Noranda reports the 1984 emissions totalled 45 percent of the 1977 emissions(Q22).

Process Area	1977	1982
Noranda Reactor	423	89
Reverberatory Furnace	4920	1033
Converters	3000	630
TOTAL	8343	1592

Table 3.1.6-4
Particulate emissions from the three main process areas during 1977 and 1982. Emissions are in tonnes per year. The 1982 emissions are based on the 1977 emissions multiplied by 0.21 (21%).

3.1.7 Noranda Gaspé

The Gaspé operation smelts a mix of custom and internally produced concentrates. Operations were modified in 1982 to meet Noranda's copper production requirements and concentrate availability(Q12). The flowsheet currently consists of a wet-concentrate fed reverberatory furnace and two Peirce Smith converters as shown in Figure 3.1.7-1. Gases from the converters are treated in a sulphuric acid plant rated at 1000 tpd. Gas from the reverberatory furnace is cleaned in an electrostatic precipitator and vented through a 152 metre stack together with the acid plant tail-gas.

Copper production in 1983 was reported at about 130 mtpd equivalent to about 540 mtpd of copper concentrate. An example of the range of composition of concentrates(Q20) treated at Gaspé is shown in Table 3.1.7-1.

A summary of the pollution control equipment in place at the Gaspé smelter is shown in Table 3.1.7-2 as discussed above.

Stack particulate emissions are in the process of being identified at Gaspé as discussed in Section 3.3.8. Limited emission sampling results are available for the acid plant and process gasses feeding it. Emissions from the reverberatory furnace have not been reported separately. Table 3.1.7-3 summarizes available data(Q11, Q23).

Data on fugitive emissions are not available however, the reverberatory furnace and Peirce-Smith converters are usual sources.

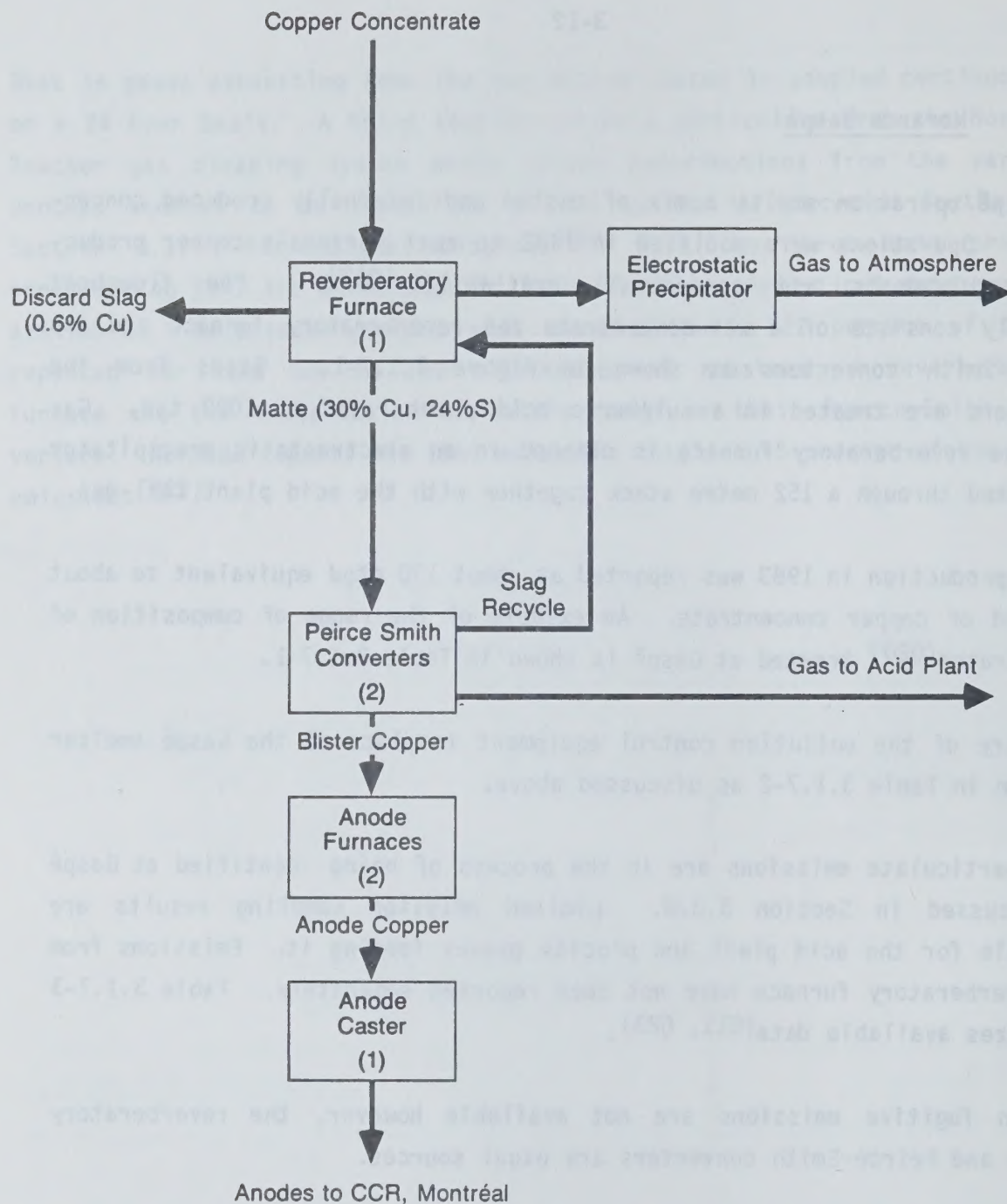


Figure 3.1.7-1
Gaspé Smelter Flowsheet

TABLE 3.1.7-1

EXAMPLE OF RANGE OF COMPOSITION OF
CONCENTRATES SMELTED AT NORNADA, GASPE (1983)

Material	Assay wt. %								
	Cu	S	Fe	Pb	Zn	As	Hg	Sb	Bi
							ppm	ppm	ppm
Copper Concentrate Blends	18-40*	10-35	15-33	1-7	0.1-8	0.02-1.0	1-300	5 - 445	3-725

* indicates range

TABLE 3.1.7-2

SUMMARY OF POLLUTION CONTROL
EQUIPMENT AT THE GASPE SMELTER

Process Area	Particulate Control Equipment
Reverberatory Furnace	Electrostatic Precipitator
Peirce Smith Converters	Cooling Chambers, Electrostatic Precipitators, Sulphuric Acid Plant

TABLE 3.1.7-3

PARTIAL EMISSIONS FROM GASPÉ SMELTER

Source	particulate (tonnes per 365 days)			
	Total	Pb	As	Hg
Acid Plant Tailgas Q11)	57	0.5	<0.3	0.001
Smelter Stack (Q23)	-	86.9	-	-

3.1.8 Brunswick Smelting - Belledune, New Brunswick

Operations commenced in September of 1966. The plant was originally designed for lead and zinc production, however, it was modified in the early seventies to produce lead only. The current operation flowsheet is depicted in Fig. 3.1.8-1. Lead concentrate, fluxes, and other recycle materials are sintered producing an agglomerated feed suitable for the blast furnace. Gas from the sinter strand is cleaned in an electrostatic precipitator and gas cleaning section of a sulphuric acid production plant prior to the conversion of the SO_2 in the gas to sulphuric acid. Tail gas from the acid plant is vented to the atmosphere through a 61 metre stack. Little particulate is emitted from the acid plant stack. General ventilation gases from the sinter plant are cleaned in a baghouse and vented.

Lead bullion is produced in a blast furnace. Off-gas from the furnace is cleaned in a baghouse and vented.

Gas from operations in the lead bullion refinery are vented into a system which incorporates a baghouse for particulate removal.

The smelter is designed to produce about 55,000 mtpy of refined lead. Concentrates treated at Brunswick are iron rich compared to many other smelting operations resulting in a large slag fall and high coke use. A typical composition of concentrate treated at Brunswick Smelting is shown in Table 3.1.8-1.

A summary of pollution control equipment operated by Brunswick Smelting is shown in Table 3.1.8-2.

Stack particulate emissions are outlined in Table 3.1.8-3. Data on fugitive are not available. Fugitives likely escape mainly from the blast furnace and sinter machine.

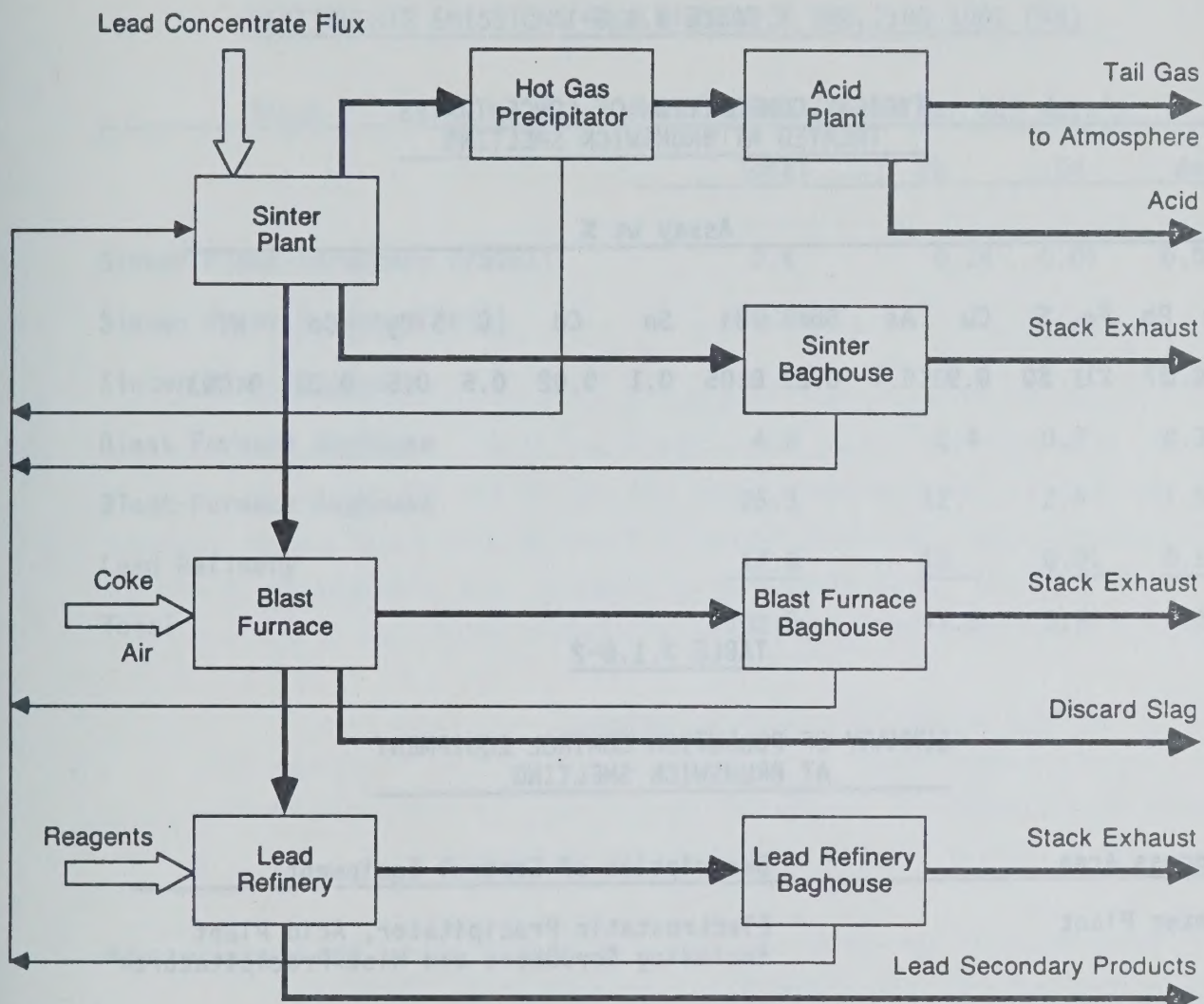


Figure 3.1.8-1

Brunswick Mining and Smelting Process Flowsheet

TABLE 3.1.8-1

TYPICAL COMPOSITION OF CONCENTRATES
TREATED AT BRUNSWICK SMELTING

Assay wt %													
Zn	Pb	Fe	S	Cu	As	Sb	Bi	Sn	Cd	C	SiO ₂	Co	Ni
7	37	21	30	0.9	0.4	0.2	0.05	0.1	0.02	0.5	0.5	0.03	0.003

TABLE 3.1.8-2

SUMMARY OF POLLUTION CONTROL EQUIPMENT
AT BRUNSWICK SMELTING

Process Area	Description of Control Equipment
Sinter Plant	Electrostatic Precipitator, Acid Plant including Scrubbers and Mist Precipitators
Blast Furnace	Baghouse
Lead Refinery	Baghouse

TABLE 3.1.8-3

PARTICULATE EMISSIONS FROM BRUSNWICK SMELTING 1982 (N5)

Stack	Particulate (tonne per 365 days*)			
	Total	Pb	Cd	As
Sinter Plant Scrubbers (P5051)	0.4	0.14	0.01	0.02
Sinter Plant Scrubber (P52)	0.04			
Sinter Plant Baghouse	52.2	20.	1.1	0.8
Blast Furnace Baghouse	4.8	2.4	0.2	0.3
Blast Furnace Baghouse	26.3	12.	2.4	1.5
Lead Refinery	<u>17.8</u>	<u>13.</u>	<u>0.01</u>	<u>0.5</u>
Total	101.5	47.5	3.7	3.1

*daily rate x 365

3.2 Climatic Setting

Summary descriptions of the climatic setting for the eight smelters being reviewed follow. The impact of the local climates on the behaviour of particulate emissions is discussed in Section 4.

3.2.1 Climate at Inco Sudbury

Inco's Copper Cliff operation is about 8 km west of the City of Sudbury, Ontario, at an altitude about 300 m above sea level. The area is underlain (032) by rock of the Precambrian era and set in the rolling countryside of the Canadian Shield. The countryside is forested with mixed boreal coniferous trees. Wind, temperature, precipitation, and atmospheric stability patterns are outlined in Figure 3.2-1A and Tables 3.2-1 to 3.2-3.

3.2.2 Climate at the Falconbridge Smelter

Falconbridge's smelter is located 20 km northeast of the City of Sudbury and has a climate similar to that described for Inco Sudbury.

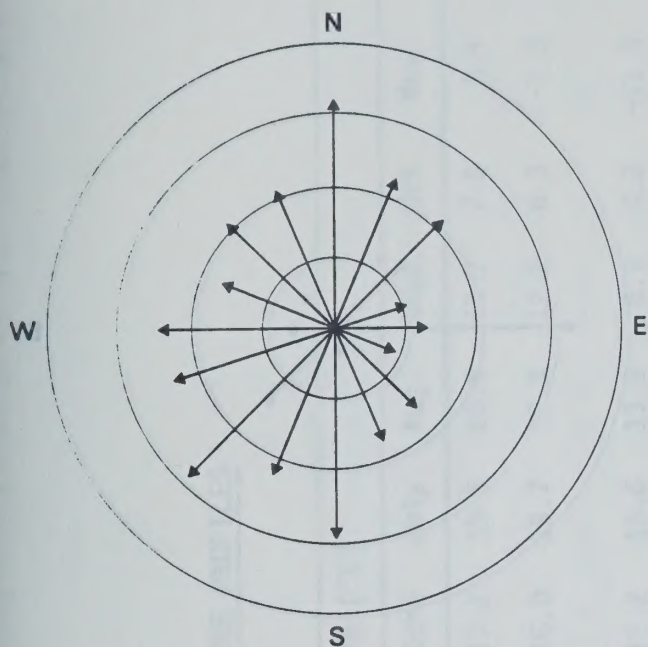
Wind, temperature, precipitation, and atmospheric stability patterns are shown in Figure 3.2-1A and Tables 3.2-1 to 3.2-3.

3.2.3 Climate at Inco Thompson

The Thompson area has a climate characterized by short, cool summers and long, cold winters. The weather is dominated by cold air masses most of the winter with occasional invasions of warmer air from the south. The mean annual temperature range is very broad. Precipitation is moderate to light with most of the precipitation occurring in the summer. Temperature, precipitation, and atmospheric stability patterns are outlined in Tables 3.2-1 to 3.2-3.

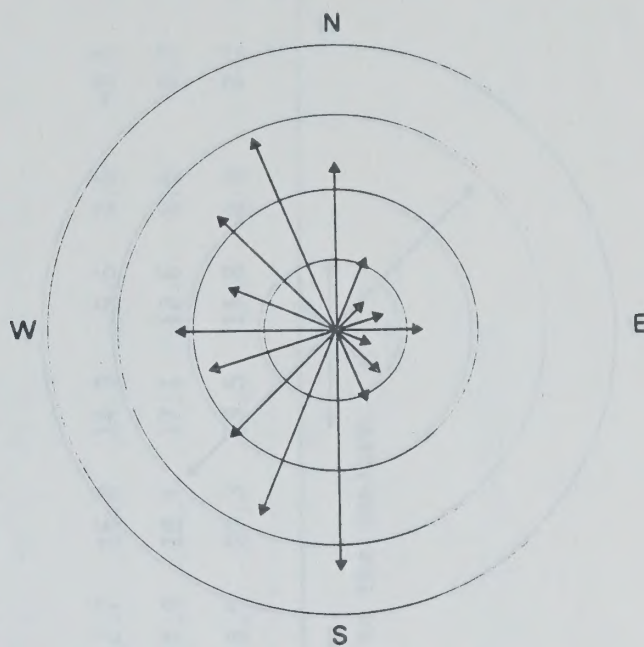
**Sudbury
Inco & Falconbridge**

Calm 2.5%



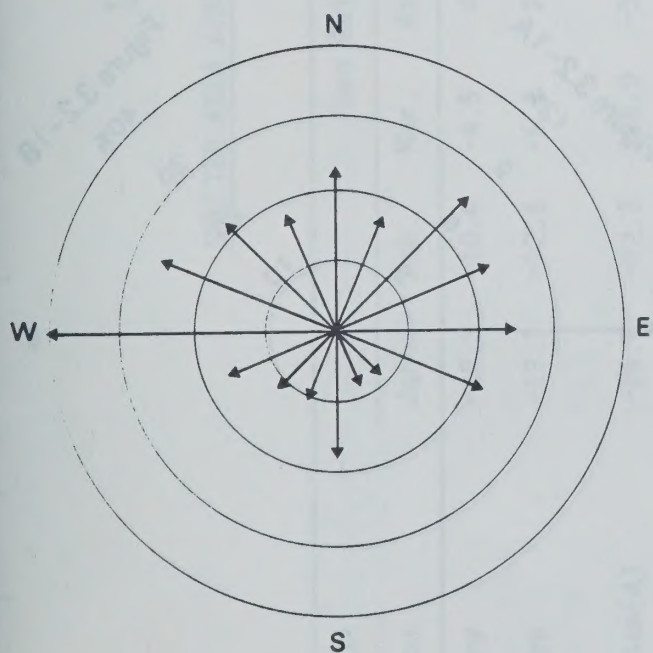
**Rouyn
Noranda-Horne**

Calm 14.9%



Thompson

Calm 12%



Murdochville (Gaspé)

Calm 20.4%

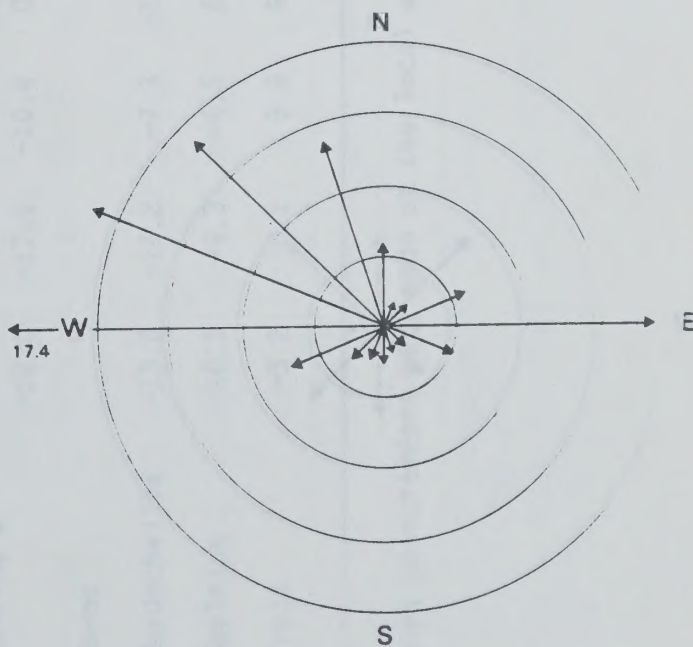
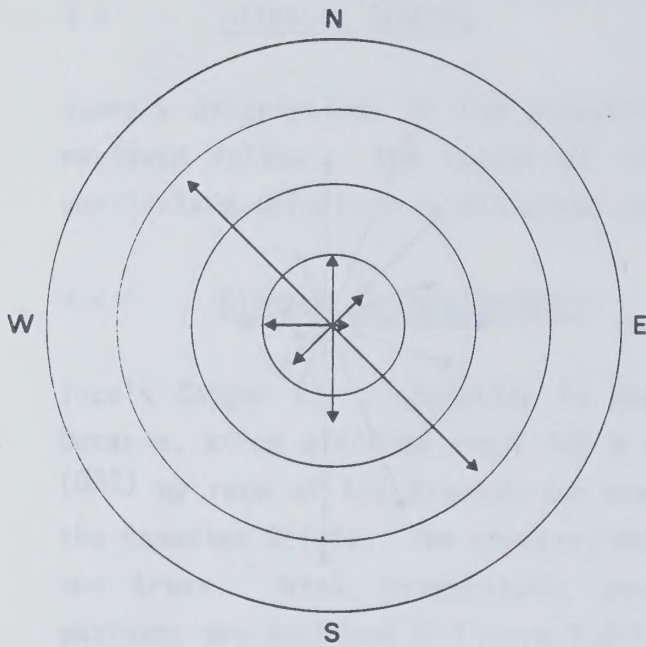
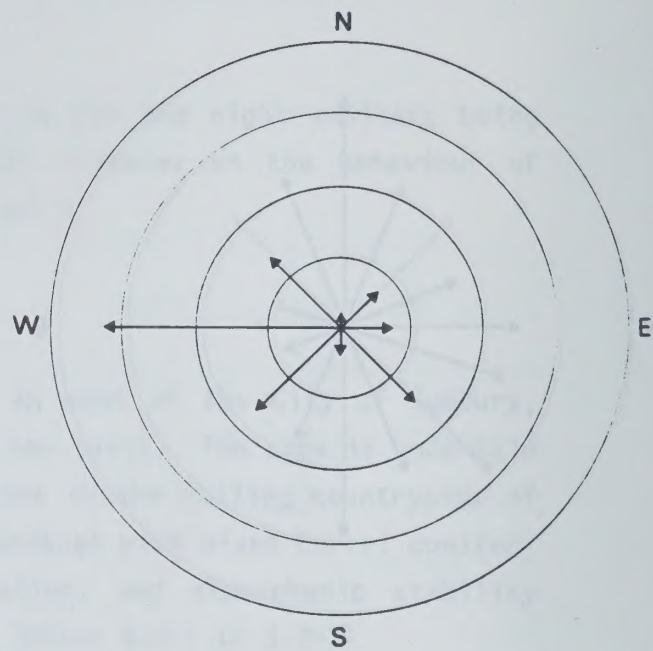


Figure 3.2-1A Frequency Percentage of Wind Direction

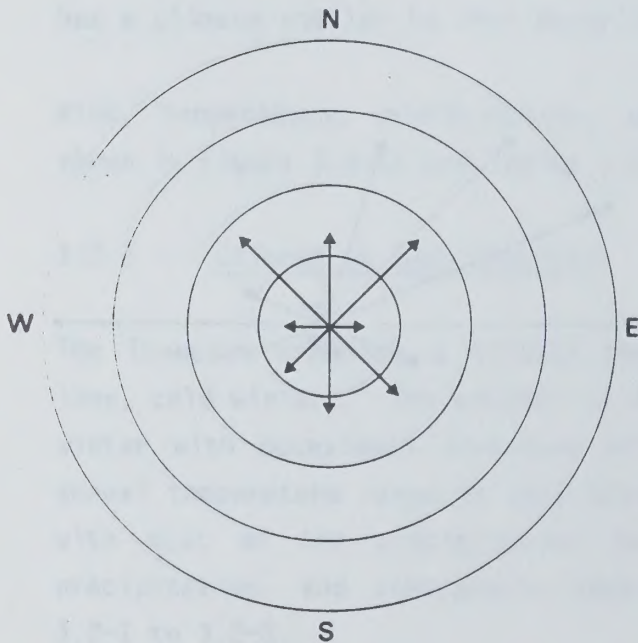
Trail
Calm 0.6%



Belledune
Calm 0.5%



HBM & S
Calm 4.7%



Legend

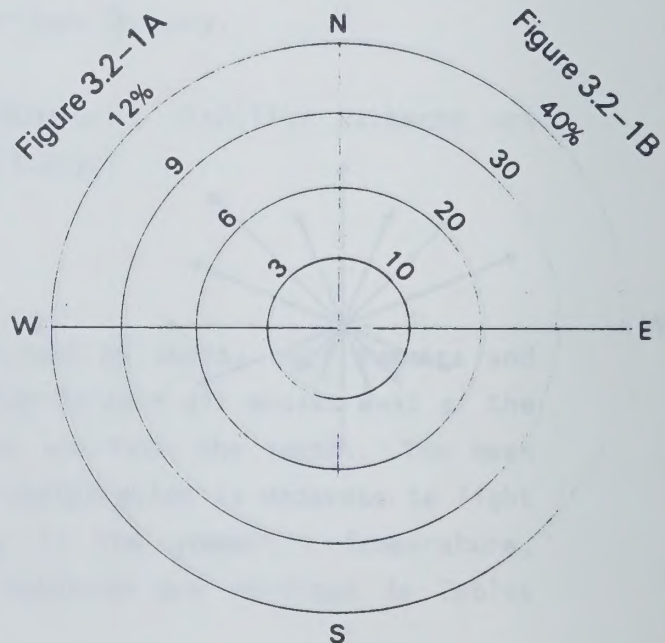


Figure 3.2-1B Frequency Percentage of Wind Direction

TABLE 3.2-1

SMELTER AREA ANNUAL TEMPERATURE PROFILES

Operation	Mean Daily Temperature (°C)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Inco Sudbury	-12.3	-10.4	-4.5	4.0	11.7	17.2	19.8	18.4	13.7	7.8	0.4	-8.1
Falconbridge Sudbury(A)	-13.7	-12.5	-6	2.7	10.5	16.0	18.7	17.3	12.2	6.3	-1.2	-10.2
Inco Thompson(A)	-26.6	-22.3	-14.9	-3.7	5.0	12.2	15.6	13.9	6.9	0.2	-11.9	-21.7
Hudson Bay Mining & Smelting	-22.4	-17.1	-10.4	0.7	9.0	15.0	18.2	16.5	9.6	3.3	-7.9	-17.5
Noranda - Horne												
Noranda - Murdochville	-13.0	-12.2	-7.3	-1.2	5.8	12.7	15.8	14.3	9.5	3.6	-2.5	-9.9
Brunswick Smelting	-10.1	-9.3	-4.5	6.6	8.1	14.9	18.4	17.1	12.6	6.8	0.9	-6.7
Cominco - Trail	-3.2	0.1	3.6	9.0	13.7	16.9	20.3	19.5	14.8	8.8	2.2	-1.5

A - indicates measurements were made at the local airport close to the smelter.

TABLE 3.2-2

SMELTER AREA ANNUAL TOTAL** PRECIPITATION (mm) PROFILES

Operation	Mean Precipitation (mm/month)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Inco-Sudbury	59.1	41.3	54.3	55.6	61.1	74.4	73.8	72.7	99.4	72.2	67.7	61.5	794
Falconbridge-Sudbury*	57.5	47.0	55.2	61.1	67.1	82.8	83.1	82.9	106.5	74.6	77.8	65.0	861
Inco-Thompson*	27.7	9.7	29.0	33.5	43.7	57.5	93.1	71.9	64.1	48.6	31.1	38.5	542
Hudson Bay Mining & Smelting-Flin Flon	19.2	17.2	20.7	22.7	36.8	60.4	64.2	67.4	58.6	30.7	25.6	22.4	446
Cominco - Trail	90.7	66.0	57.3	41.0	55.4	55.7	29.6	40.4	37.9	50.5	82.3	96.6	703
Noranda - Horne***	41.3	32.5	41.4	45.6	70.2	97.5	93.8	102.7	114.	75.0	61.0	47.7	823
Noranda - Gaspé	90.6	76.1	99.7	68.4	56.4	75.4	105.1	91.5	79.0	95.1	95.1	110.5	1034
Brunswick Smelting	90.8	82.8	98.0	71.1	76.1	72.3	78.0	78.7	72.7	83.2	83.2	115.7	998

* measured at nearby airport

** total precipitation is recorded as rainfall plus measured water equivalent of snowfall

*** measured at La Sarre

TABLE 3.2-3

ANNUAL DISTRIBUTION OF STABILITY %*

Stability Category	Description	Sudbury	Thompson	Flin Flon	Castle** Gare	Rouyn	Gaspé	Charlo°
A	Very Unstable	0.8	0.2	0.5	2.3	0.9	0.3	0.4
B	Moderately Unstable	5.1	4.0	10.8	12.3	7.4	4.2	4.4
C	Slightly Unstable	8.6	10.4	19.7	14.5	13.2	12.5	8.7
D	Neutral, daytime	27.7	28.6	44.5	23.0	39.0	36.0	29.7
D	Neutral, nighttime	41.7	22.8	11.1	20.5	19.4	22.9	31.0
E & F	Moderately to Very Stable	16.3	34.0	13.4	27.3	20.0	24.1	25.0

* calm periods distributed within categories

** Airport north of Cominco Trail

^ Airport east of Murdochville

o Airport north of Belledune

The wind direction frequencies are shown in Figure 3.2-1A. The predominant winds are westerly and northwesterly. Minisonde observations have further determined that upper level winds at the stack height (152 m) tend to veer (clockwise) relative to ground level winds (MEP, 1979). Atmospheric stability patterns for Thompson are summarized in Table 3.2-3.

3.2.4 Climate at Hudson Bay Mining and Smelting

Smelting operations at Hudson Bay Mining and Smelting are located just northwest of Flin Flon, Manitoba. The surrounding countryside is generally rocky, rolling, tree covered and replete with numerous lakes.

Wind, temperature, precipitation, and atmospheric stability patterns are outlined in Figure 3.2-1B and Tables 3.2-1 to 3.2-3.

3.2.5 Climate at Noranda Horne

Noranda operates the Horne smelter on the northerly edge of the town of Noranda, Quebec. The surrounding area is slightly mountainous and partly wooded.

Wind, temperature, precipitation, and atmospheric stability patterns are summarized in Figure 3.2-1A and Tables 3.2-1 to 3.2-3.

3.2.6 Climate at Noranda Murdochville

Noranda mining-smelting complex at Murdochville, Quebec, is located in the rolling hills of the Gaspé peninsula about 40 km south of the St. Lawrence river.

Wind, temperature, precipitation and atmospheric stability patterns are outlined in Figure 3.2-1A and Tables 3.2-1 to 3.2-3.

3.2.7 Climate at Brunswick Smelting - Belledune

Brunswick Smelting at Belledune, New Brunswick operates at a coastal location beside the Town of Belledune on the Baie des Chaleurs. The surrounding countryside is flat and relatively open^(G31) and slopes gently toward the Baie des Chaleurs.

Wind, temperature, precipitation and atmospheric stability patterns are outlined in Figure 3.2-1B and Tables 3.2-1 to 3.2-3.

At Belledune, the prevailing winds are westerly, with northerly and southerly winds forming a small percentage of the total wind frequency.

Belledune has a moderate climate with daily mean temperatures of about 18°C in July.

The annual rainfall is about 1,000 mm.

3.2.8 Climate at Cominco - Trail

Cominco's Trail operation is located in the Columbia River Valley between the United States Border and Castlegar, B.C. The valleys in the area are narrow, generally only 2 or 3 km in width, and steep sided. There are many mountains in the region with elevations greater than 2000 metres. The Selkirk range is generally oriented north and south in the region.

Moderate annual precipitation, warm summers, and fairly mild winters characterize the climate of the valley areas. Mean minimum temperatures range from about -7°C in January and 12°C in July, while mean maximums range from about zero to the high twenties in the same months. Temperatures in the mountains are five to ten degrees colder. Precipitation is relatively uniformly distributed throughout the year, totalling 500 to 600 mm in the

valleys and over 800 mm in the mountains. Persistent inversions can occur during the winter when cold air is trapped in the bottom of the valleys. In the summer, inversions occur when the area is under the influence of stagnant high pressure areas, and surface-based nocturnal inversions can be expected.

Wind temperature, precipitation and atmospheric stability patterns are summarized in Figure 3.2.1-B and Tables 3.2-1 to 3.2-2.

3.3 REGULATORY CONTROLS, PLANT PRACTICES AND EMISSION SAMPLING PROGRAMS

3.3.1 Background

The smelters being reviewed have, due to a variety of pressures and interests, developed operating practices and process sampling programs which both identify and moderate heavy metal emissions. Some plants have regulatory commitments which limit SO₂ emissions and, as a result, heavy metal particulate emissions. Other programs are intended primarily to monitor metal losses and provide data for metallurgical accounting purposes. The following smelter control and sampling program descriptions are based on interviews with plant personnel.

Applicable regulation citations, extracted from current provincial regulations, are summarized.

3.3.2 Controls, Practices and Sampling Programs at Inco - Sudbury

Inco's smelting operation in Sudbury utilizes meteorological data, weather models and SO₂ monitors in the region to forecast situations which would produce excessive ground level concentrations (GLC's). Production changes are used to ensure GLC requirements are maintained.

It is likely reductions in local SO₂ levels also reduce the local dust fall-out.

Inco's Environmental Control department maintains the SO₂ control system described above and other monitoring programs. The Process Technology department carries out process and stack emission measurements.

3.3.3 Controls, Practices and Sampling Programs at Falconbridge - Sudbury

The Falconbridge smelting operation⁽⁰⁵¹⁾ is integrated into a computerized network of continuous SO₂ monitors operated by the company (3 sites) the MOE (approx. 25 stations).

By controlling production (principally matte converting) to limit SO₂ GLC's, to 0.5 ppm over one hour, particulates associated with SO₂ emissions impinging locally are likely reduced. Heavy metal emissions are monitored as follows:

- i. the Smelter Ventilation Department carries out sampling on the main stack. A group of 3 regular plus one temporary technician is required; sampling follows the EPA - 5 test method but with a fixed position probe.
- ii. stack sampling has been routinely carried out on an annual basis up to and including 1983. Sampling was curtailed in 1984.
- iii. monitoring of stack emissions is planned in 1985 when smelting operations are modified to include greater emphasis on scrap processing; routine sampling is not planned after 1985. Requests by the MOE for stack tests will be considered special programs.

Falconbridge does not operate other programs to monitor off-site effects of heavy metals from stacks or as low-level fugitives and has no immediate plans to implement any programs.

3.3.4 Controls, Practices and Sampling Programs at Inco - Thompson

Inco's Thompson operation (M28) maintains an environmental control department which carries out occupational exposure monitoring in-plant and ambient monitoring in the surrounding area. This includes monitoring to conform with the requirements of the Order governing emissions from the Thompson operation issued by the Manitoba Clean Environment Commission.

Air quality at Thompson is monitored as follows:

- i. Stack sampling is completed annually, with a representative from the Environmental Management Division of the Manitoba Environment Department. Results are reported to the Environmental Management Division and are used to calibrate an in situ continuous stack monitor.
- ii. Daily SO₂ concentrations (calculated from mass balance) and particulate emissions (from stack monitor) are reported each month to the E.M. Division.
- iii. Two dustfall monitoring sites are located in plant area. Four dustfall and sulphation plate sites are operated in city of Thompson and sampled monthly. Results reported to the Environmental Management Division.
- iv. A continuous SO₂ monitor operates in the City of Thompson. Portable monitors used during spring and summer record SO₂ levels. Results of continuous monitoring are reported to the Environmental Management Division.
- v. Soil, vegetation, water surveys within a 100-mile radius were carried out annually to 1977. The current program is less intense and is being updated less frequently.

Inco Thompson particulate emissions are regulated by the Manitoba Clean Environment Commission (M20) which issued regulations for the smelting operation at Thompson in 1983.

3.3.5 Controls, Practices, and Emission Sampling Program at HBM&S

Hudson Bay Mining and Smelting (HBM&S) maintains a stack sampling group made up of one full-time technician and two part-time support personnel. (M29) Analytical work is carried out separately by the in-house laboratory.

Emissions of heavy metals from the plant are monitored as follows:

- i. "official" sampling of the main stack is completed annually; this is a requirement of HBM&S' pollution control permit.
- ii. the main stack and gas streams from various sources feeding the main stack are monitored during the year to monitor the performance of the gas cleaning systems
- iii. emissions from other short process and ventilation stacks, each less than 15 metres high, are monitored from time to time to determine the efficiency of up-stream gas cleaning systems.
- iv. measurements of fugitives from sources such as roof-top monitors are not attempted.

An environmental control group consisting of seven full-time engineers and technicians who, among other duties, maintain the following network:

- i. two dust fallout stations within a distance of about 3 km from the plant; this program has been in operation for about 15 years and has included as many as 20 sampling stations.
- ii. two high-volume sampling stations at distances of about 4 and 0.8 km from the plant.

- iii. approximately every 3 years, all major lakes and water systems within; 250 km of the plant are sampled for heavy metal and other constituent 3 such surveys have been undertaken during the last 10 years.

HBM&S is not conducting other environmental impact studies and has no plans to do so in the immediate future.

The smelting operation at HBM&S falls under the regulation of the Manitoba Clean Environment Commission which issued a site permit^(M21) in 1981.

3.3.6 Controls, Practices, and Emissions Sampling Programs at Cominco - Trail

Cominco operates a network^(B17) of seven continuous SO₂ monitoring stations including one located in the State of Washington. Telemetry data from the stations produce ground level concentrations (GLC's) that are used to regulate production. A staff of four technicians monitor the network on a 24-hour basis and initiate production cut-backs to avoid exceeding SO₂ GLC limits.

Four of the SO₂ stations are equipped to measure particulate in ambient air. Dust samples are subsequently analyzed for TSP, Pb, Zn, Cd and As. This program is supported by Cominco analytical and instrumentation personnel. Cominco also maintains an array of sulphation plates, fluoride plates and settling jars at sites which cover an area extending 32 km north and 37 km south of Trail.

The Waste Control Department, comprised of 15 technicians carries out stack, ventilation, and workplace gas and dust sampling. Stacks are monitored as a requirement of the pollution control permit under which Cominco operates. Some 50 stacks are sampled for various parameters, at specific frequencies laid out in the permit. Low level fugitives are not measured directly.

Cominco operates a vegetation and soil sampling program in the Trail area. Garden vegetables are collected annually, analyzed and the results disseminated to the growers. No other metal impact programs are in progress.

Cominco emissions are regulated by the British Columbia Ministry of the Environment which issued permits and variance orders for the Trail operation as outlined in Table 4.6.1.

3.3.7 Controls, Practices and Sampling Programs at Noranda - Horne

The Horne smelter operates a network of continuous dust sampling devices on process streams. Continuous dust samplers have been developed in-house for stacks and flues. Currently, the two active stacks are sampled on a 24-hour basis. Sampling conditions are controlled automatically to maintain isokinetic flows at the probe. A third continuous sampler measures particulate from the Noranda Reactor gas cleaning system. With the three samplers operating, contributions from the main sources in the plant can be established.

Noranda maintains a Technical Service Group which carries out in-plant dust sampling programs: two are assigned to the daily routine sampling, and a team of seven, as part of their duties, assure the verification and calibration of the sampling equipment, as well as other dust sampling activities, as required for control purposes and improvement projects. (This is in addition to an operating crew of 13, which assures the operation and maintenance on a continuous basis of six electrostatic precipitators.)

Off-site measurements are organized as follows:

- i. three Hi-vol samplers are stationed at points about 0.8 to 3 km from the plant;
- ii. eight dust fallout collectors are located at distances of about 3 and 6 km from the plant on the cardinal compass points;
- iii. a crew of 5 technicians maintains off-site dust sampling equipment and soil sampling programs. Noranda does not publish the soil composition results.
- iv. results from SO₂ monitors off-site are analyzed on a 24-hour basis by the same crew as above to maintain acceptable GLC's in the local environs (Intermittent Control System).

3.3.8 Controls, Practices, and Sampling Programs at Noranda-Gaspé

Mines Gaspe maintains a department of "Services de l'Environnement" to carry out emission monitoring programs. This group consists of a coordinator and two technicians.

The main stack is sampled using a continuous in-stack device operating on a "balanced" draft basis. Noranda developed a continuous sampler which is also used at their Horne operation, as discussed in Section 4.7. The stack sampler is to be compared with state-of-the-art stack sampling procedures in 1985 for calibration purposes. Stack data reporting is limited to an in-house distribution and the Quebec Ministere de l'Environnement on an annual basis. Fugitive emissions are not sampled at Gaspe, but there is some interest in sampling their short vent stacks.

Gaspé operates a high-volume sampler in the town site of Murdochville. Operation is every second or third day for a 24 hour period. Captured dust samples are analyzed for total weight and heavy metals Cu, Fe, Zn, As, Cd, Pb. In addition, a network of 12 dustfall stations located within 15 km of the plant are maintained. Samples are analyzed for each month for total particulate and heavy metals. Snow and water samples from lakes 15 to 30 km from the site are also collected and analyzed.

Gaspé has never undertaken in-house environmental impact studies on vegetation, animal or human life forms, but has collaborated on one program.(Q20)

3.3.9 Controls, Practices and Sampling Programs at Brunswick Smelting

Brunswick operates an environmental control department which consists of an environmental control coordinator and two technicians.

Air quality around the plant is monitored as follows:

- i. Stack sampling is completed annually. Currently, seven operating stacks are monitored (excluding the acid plant stack, which is virtually dust free).
- ii. Plume fallout is monitored at 3 locations close to the plant using conventional high-volume samplers. These stations are within 2 miles of the plant.
- iii. Sampling of dust fallout is carried out using fallout buckets to a radius of 11 km from the plant. This program will be phased out due to interferences from other emission sources. The sampling routine described in 'ii' will remain as the principal source of heavy metal ambient and fallout data.
- iv. Soil and vegetation sampling programs are implemented annually as follows:
 - local forage is sampled 4 times a year;
 - vegetables from 13 gardens are sampled once a year (specimens are collected from as far away as Bathurst, N.B.).
 - soil sampling is currently completed once a year but will soon decrease to every five years to a radius of 11 km from the plant.

Results of the annual stack sampling are reported to Environment New Brunswick as part of the requirements in the pollution control permit issued to Brunswick Smelting. The permit is currently being revised.

3.3.10 Summary of Pollution Control Regulations for the Major Canadian Non-ferrous Smelters

A listing of current environmental pollution control regulations applicable to the smelters studied is shown in Table 3.10-1.

SUMMARY LISTING OF POLLUTION CONTROL REGULATIONS EFFECTING PARTICULATE EMISSIONS

Operation	Regulation Description	Particulate Reduction Aspect
Inco Sudbury	i. Ontario Ministry of the Environment (MOE), Reg. 308 Environmental Protection Act 1981 ii. Amending Control Order 1983	Limits Ground Level Concentrations of Heavy Metals Limits SO ₂
Falconbridge Sudbury	i. MOE Reg. 308 Environmental Protection Act 1981 ii. Amending Control Order 1983	Limits Ground Level Concentrations of Heavy Metals Limits SO ₂
Inco Thompson	Order of the Clean Environment Commission of Manitoba, Permit No. 483V000 Mar. 1983	Limits Stack Emissions
Hudson Bay Mining and Smelting	Order of the Clean Environment Commission of Manitoba, Permit No. 899V0 April 1981	Limits Stack Emissions
Cominco Trail	Pollution Control Act Permits for Cominco Lead and Zinc Smelters - PA-2692, 2691	Limits Stack Emissions
Brunswick Smelting	Certificate of Approval, New Brunswick Air Quality Regulations, Reg. 79-43	Limits Stack Emissions and Describes Off-site Measurements Necessary
Noranda Horne	Quebec Environment Quality Act, Reg. Q-2, Sept. 1982	Limits Ground Level Concentrations not Plant Emissions
Noranda Gaspe	Quebec Environment Quality Act, Reg. Q-2, Sept. 1982	Limits Ground Level Concentrations not Plant Emissions

4.0 HEAVY METALS DISPERSION

The air quality chapter summarizes, for each smelter, relevant available information on: 1) concentrations of heavy metals in ambient air; 2) local deposition rates of heavy metals and; 3) long range transport of heavy metals.

The quantity of available data for each of the smelters varied considerably. While extensive sets of both raw and summarized data could be used to describe the effects of Inco and Falconbridge emissions on air quality in the Sudbury area, no data were available to Noranda's Murdochville smelter. In general, the available data were not recent. As discussed in Section 3.3, operators of some smelters apparently possess air quality survey data in unpublished form.

The types of data available for each smelter also varied. Precipitation chemistry data were available only from the Sudbury area. Dry deposition rates were measured using dustfall jars at three smelters and by modelling from ambient air data at Sudbury. Estimates of total deposition rates (by snow sampling and/or moss traps) were available from three smelters. Ambient air data, including heavy metals, were also available from three smelters. Information on long-range transport of heavy metals was generally unavailable.

4.1 Inco and Falconbridge - Sudbury

The principal sources of air quality data in the Sudbury area are reports prepared by the Ontario Ministry of the Environment as part of the Sudbury Environmental Study. As these reports present data applicable to both the Falconbridge and Inco smelters, the two smelters are conveniently discussed in one Section. Relative contributions of heavy metals to the air environment by each smelter are described where possible.

4.1.1 Local Ambient Air Concentrations

Hi-vol sampling was conducted over a period of two years at eight sites in the Sudbury area as part of the Sudbury Environmental Study (MOE, 1982; Ref. 06). Data from three of these sites, one near each of the two smelters and a site 30 km to the southwest, are summarized in Table 4.1.1. Copper data have not been included because of analytical and sampling problems, but copper concentrations are expected to be generally similar to those of nickel (MOE, 1982; Ref. 015).

Mean nickel concentrations near the smelters ($0.016 \mu\text{g}/\text{m}^3$) were eight times higher than at the distant site. Concentrations of lead, zinc, cadmium and aluminum were also elevated near the smelters, but to a much lesser extent. The limited arsenic and selenium data also suggest some smelter contributions.

Concentrations of heavy metals in the plumes from Inco and Falconbridge relative to background concentrations at the time of sampling are shown in Table 4.1.2. The large influence that the smelters (particularly Inco) have on ambient nickel concentrations (7-25 times background) is particularly evident from these data. The influences of each of the smelters on the concentrations of other metals appear to be similar and amount to increases of 130-290%, depending on the metal.

The plumes from both Inco and Falconbridge measurably influence ambient metal concentrations for at least 40 km from their stacks (see Table 4.1.3). Inco's influence is much greater than that of Falconbridge, especially with respect to nickel, and presumably copper (Ref. 015).

TABLE 4.1.1

CONCENTRATIONS OF HEAVY METALS IN AMBIENT AIR IN THE SUDBURY AREA
FROM HI-VOL SAMPLING JULY, 1978 TO MAY, 1980¹

	$\mu\text{g}/\text{m}^3$ (Geometric mean and range)		
	Ash Street ²	Happy Valley ³	Lake ⁴ Penage
Ni	.016 .001-.732	.016 .001-.220	.002 .001-.287
Pb	.102 .002-.563	.031 .002-.226	.018 .002-.334
Zn	.039 .005-.250	.023 .005-.299	.019 .005-.130
Cd	.001 .000-.032	.001 .000-.030	.000 .000-.012
Al	.162 .045-1.31	.121 .045-1.05	.064 .045-.738
As	.004 .003-.004	-	.001 .000-.011
Se	.007 .006-.010	-	.001 .000-.003

¹ from Ref. 06² approx. 4 km east of superstack; n = 141-218, except As, Se (3)³ approx. 1 km south of Falconbridge; n = 86-118⁴ approx. 30 km south-west of superstack; n= 150-215, except As, Se (8,7)

TABLE 4.1.2

RELATIVE BACKGROUND, INCO PLUME AND FALCONBRIDGE
PLUME CONCENTRATIONS OF HEAVY METALS, JULY, 1978 TO MAY, 1980¹

METAL	Mean Concentrations ($\mu\text{g}/\text{m}^3$)					
	INCO (n = 91-97)			FALCONBRIDGE (n = 66-108)		
	Plume*	Background	Ratio (P/B)	Plume	Background	Ratio (P/B)
Ni	.052	.002	25.4	.014	.002	7.2
Pb	.078	.034	2.3	.070	.041	1.7
Zn	.042	.024	1.7	.039	.031	1.3
Cd	.002	.001	2.0	.002	.001	1.9
Al	.182	.128	1.4	.148	.102	1.4

¹ from Ref. 015

* sampled at Hi Vol stations within 37 km of each smelter and averaged

TABLE 4.1.3

MEAN ADDITIONAL CONCENTRATIONS OF HEAVY METALS IN
AMBIENT AIR DUE TO INCO AND FALCONBRIDGE PLUMES AT
DIFFERENT DISTANCES FROM THE SMELTERS^{1, 2}

Distance from smelter (km)	$\mu\text{g}/\text{m}^3$				
	Ni	Pb	Zn	Cd	Al
Inco (n = 14 - 69) ³					
0 - 4	.124	.101	.042	.0027	.119
10	.045	.028	.013	.0007	.067
21	.023	.019	.012	.0005	.084
31	.017	.008	.004	.0001	-.011
39	.010	.005	.017	.0005	.096
Falconbridge (n = 17-106) ³					
0 - 1	.036	.017	.010	.0030	.070
15	.009	.066	.014	.0008	.042
21	.004	.019	.006	.0005	.034
37	.003	.015	.003	.0002	.026

¹ additional concentration = ambient conc. minus background conc.

² from Ref. 015

³ the number of data points was lowest at the greatest distance

4.1.2 Local Deposition Rates

Although no data have been found describing total deposition of heavy metals in the Sudbury area, detailed assessments of both dry deposition (MOE, 1982; Ref. 015 and supporting reports) and wet deposition (MOE, 1982; Ref. 07, 011 and supporting reports) have been undertaken as part of the Sudbury Environmental Study.

Dry Deposition

Dry deposition from Inco and Falconbridge emissions are shown in comparison to background desposition in Table 4.1.4. Deposition values were estimated from measured ambient air concentrations, deposition velocities determined from airborne partical sizing measurements and calculated plume sector sizes (Ref. 015). Copper data were not published but the results are expected to be very similar to those for nickel (Ref. 015).

The contributions of Inco and Falconbridge to total dry deposition within the 40 km radius study area are high for nickel (78%, 40% respectively) lead (15%, 22%) and iron (18%, 11%) but generally less than 5% for other metals (Zn, Cd, Al). The latter metals and lead occur mainly in fine particulates and very little of the smelter emissions of these metals are dry-deposited within 40 km of the smelter. Nickel, aluminum, iron and probably copper are deposited to a greater extent in this area since they are mainly associated with coarse particles. Much higher percentages of Falconbridge emissions are deposited locally because its stack is considerably lower than the Inco superstack.

Wet Deposition

Average monthly wet deposition of nickel and copper during 1979 - 1980 are shown in Figures 4.1.1 and 4.1.2. Near Sudbury, monthly values for nickel ($560 \mu\text{g}/\text{m}^2$) and copper ($440 \mu\text{g}/\text{m}^2$) are very high compared to background deposition rates of $85 \mu\text{g}/\text{m}^2$ (Ni) and $140 \mu\text{g}/\text{m}^2$ (Cu) (MOE, 1982; Ref. 011).

TABLE 4.1.4

MEAN DRY DEPOSITION OF HEAVY METALS FROM INCO AND FALCONBRIDGE
EMISSIONS AND BACKGROUND SOURCES WITHIN A RADIUS OF 40 km
OF EACH OF THE SMELTERS, JULY 1978 TO MAY 1980¹

	Emissions (kg/day)	Prorated ² deposition (kg/day)	% deposited	Background deposition (kg/day)	% ³ total
I N C O					
Ni	798	38	4.8	11	78
Pb	480	.75	.16	4.1	15
Zn	126	.23	.18	2.5	8.4
Cd	37	.007	.02	.15	4.5
Al	406	30	7.4	523	5.4
F A L C O N B R I D G E					
Ni	14	7.5	54	11.3	40
Pb	37	1.4	3.8	5.0	22
Zn	5.7	.13	.23	3.2	3.9
Cd	12	.006	.05	.15	3.9
Al	32	15	47	416	3.5

¹ from Ref. 015

² prorated by the fraction of sampling days with impingement;
total number of sampling days 174-274

³ smelter deposition/(smelter deposition + background deposition)

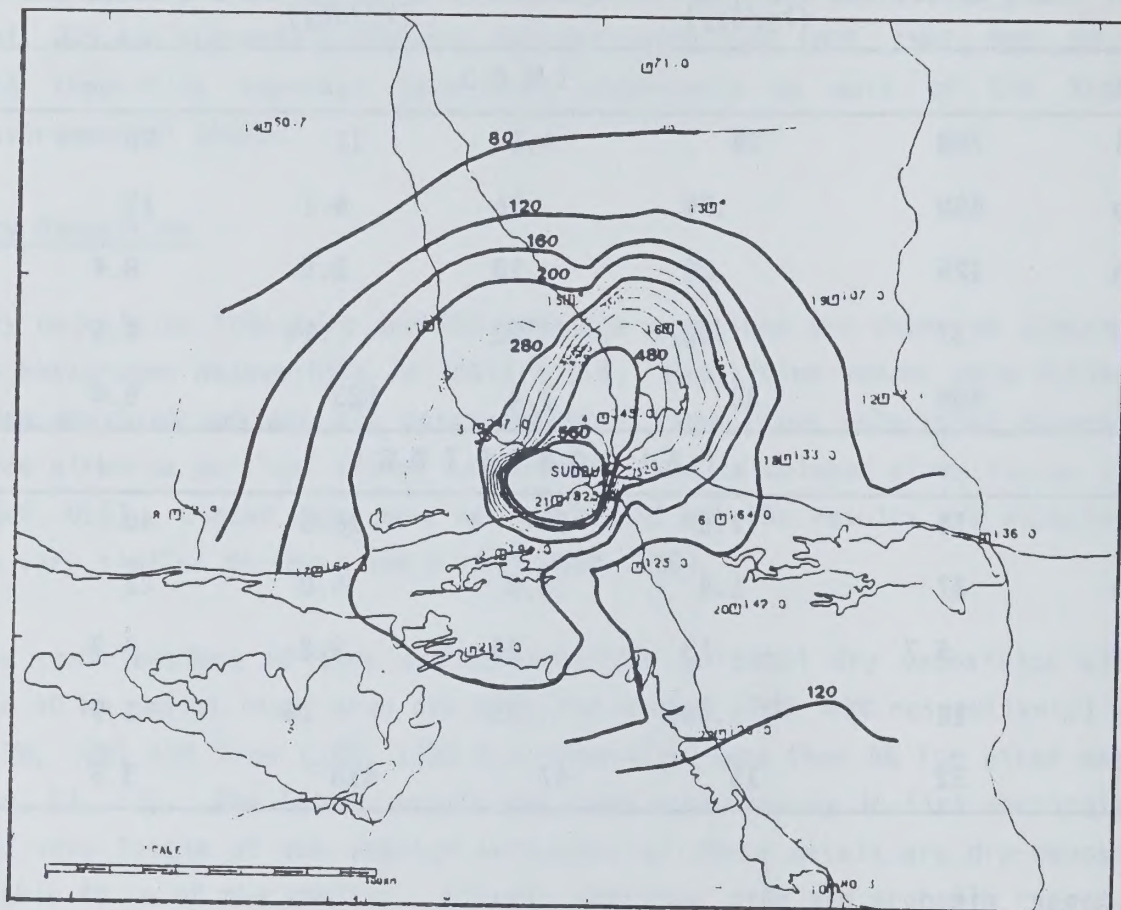


Figure 4.1.1: AVERAGE MONTHLY WET DEPOSITION ($\mu\text{g}/\text{m}^2$) OF Ni - JUNE 79 to MAY 80

SOURCE: Ref. 011

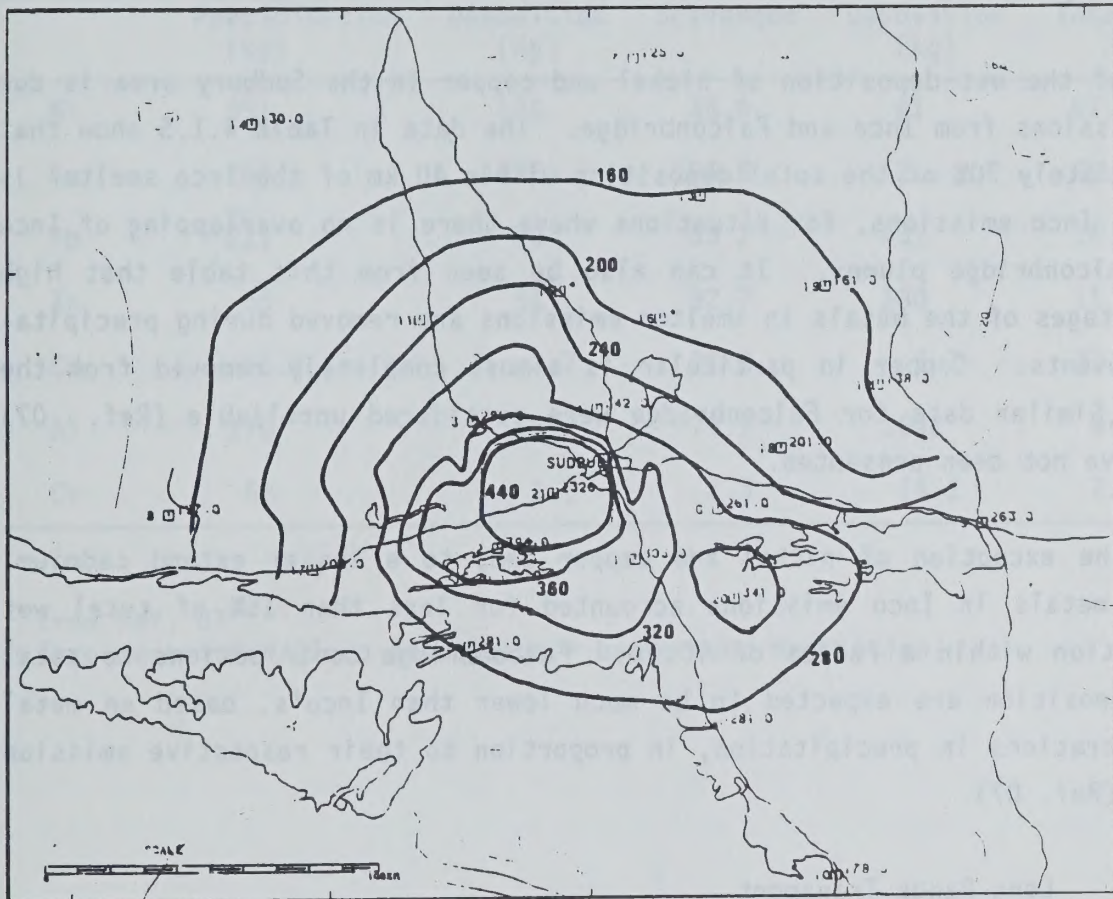


Figure 4.1.2: AVERAGE MONTHLY WET DEPOSITION ($\mu\text{g}/\text{m}^2$) of Cu - JUNE 79 TO MAY 80

SOURCE: Ref. 011

Of other metals, including zinc, chromium and cadmium, only lead deposition rates showed a detectable smelter impact. Iron and aluminum deposition appeared to be governed mostly by non-smelting phenomena, such as dust, long-range transport and vehicular traffic.

Most of the wet deposition of nickel and copper in the Sudbury area is due to emissions from Inco and Falconbridge. The data in Table 4.1.5 show that approximately 70% of the total deposition within 40 km of the Inco smelter is due to Inco emissions, for situations where there is no overlapping of Inco and Falconbridge plumes. It can also be seen from this table that high percentages of the metals in smelter emissions are removed during precipitation events. Copper in particular is almost completely removed from the air. Similar data for Falconbridge were considered unreliable (Ref. 07) and have not been presented.

With the exception of nickel and copper and, to a lesser extent cadmium, other metals in Inco emissions accounted for less than 15% of total wet deposition within a radius of 40 km. Falconbridge contributions to total wet deposition are expected to be much lower than Inco's, based on metal concentrations in precipitation, in proportion to their respective emission rates (Ref. 07).

4.1.3 Long Range Transport

It is apparent from the dry deposition data (Table 4.1.4) that most of the metals emitted from the smelters, particularly Inco, would be deposited at distances much greater than 40 km in the absence of precipitation. During precipitation events, however, a high percentage (23-100) of the principal metals in the air at that time are deposited locally.

The Acidic Precipitation in Ontario Study (APIOS), a long-term project of the Air Resources Branch of the Ontario Ministry of the Environment, operates two province-wide sampling networks. The Cumulative Wet/Dry

TABLE 4.1.5

MEAN WET DEPOSITION OF HEAVY METALS FROM INCO EMISSIONS AND
BACKGROUND SOURCES WITHIN A RADIUS OF 40 km OF EACH OF THE
SMELTERS DURING PRECIPITATION EVENTS JULY 1978 TO MAY 1980¹

	Emissions During Precipitation (kg)	Deposition (kg)	% Scavenged	Background Deposition (kg)	% ² Total
Ni	351	126	35.9	61	67.4
Cu	260	272	104.6	121	69.2
Pb	211	70	33.2	431	14.0
Zn	55	51	92.7	380	11.8
Cd	16.4	3.7	22.6	9.7	27.6
Al	178	142.2	79.9	1642	8.0
Cr	52	1.2	2.3	14.2	7.8

¹ from Ref. 07

² Inco deposition/(Inco deposition + background deposition)

Deposition Network, started in December 1981, encompasses 36 stations from which cumulative 28-day samples are collected. The results, which include concentrations of various parameters in precipitation and monthly deposition rates (in mg/m^2), are intended to examine long-term deposition patterns and trends. The analyses include five of the heavy metals of interest to the present study (Ni, Zn, Pb, Cu, Cd). Ambient air samples are also collected at 23 of the 36 stations (APIOS, 1984 - Ref. 04). The heavy metal results from this network cannot readily be used to examine long-range transport from the Sudbury area because the 28-day cumulative sampling periods obscure the influence of Sudbury's smelters as compared to other sources.

The Event Wet/Dry Deposition Network provides precipitation and air filter samples on a daily basis, but heavy metals of interest to the present study are not analysed for.

4.2 Inco-Thompson

4.2.1 Local Ambient Air Concentrations

No data were found to describe concentrations of heavy metals in ambient air. However, based on the composition of particulate stack emissions, it is expected that iron and nickel are the principal contaminants. In 1980, it was reported that 164 t of iron, 42 t of nickel, 6 t of copper, 1 t of zinc and much lower quantities of lead, cobalt, cadmium, arsenic and selenium were released in particulates from the Thompson stack (Table 3.1.3.2).

4.2.2 Local Deposition Rates

Although no data were available which directly provided deposition rates of heavy metals in the Thompson area, several related data sets can be used to obtain a general appreciation.

Ground-level dustfall rates are summarized in Table 4.2.1. Although the site-to-site data were highly variable (Phillips and Slaney 1981; Ref. M14), the summary indicates that mean dustfall rates 2-8 km from the smelter (0.2 tons/km²/month) are in the order of 3-4 times regional background levels. Six-year means for individual sites ranged from 0.04-0.59 tons/km²/month.

Moss traps were used during 1980 to determine total deposition rates of nickel and copper (Wotton and Hogan, 1981: Ref. M19). However, the data (Table 4.2.2) were presented as µg/g of moss and insufficient supplementary information was available to convert these concentrations to actual deposition rates. Nevertheless, since the moss traps were of a standard size, it is possible to interpret the data as showing that deposition rates are greatly reduced beyond 2.3-4 km from the smelter and were very close to background levels at distances greater than 12 km.

Metal concentrations in snow samples are shown in Table 4.2.3. The data for nickel and copper are very similar to the moss trap data in that very high concentrations were only found within about 4 km of the smelter. The levels of lead and arsenic may be slightly elevated near the smelter but cadmium concentrations (not shown) were at or below the limits of detection in all samples. Zinc concentrations, also not shown, ranged from .02-.056 mg/L but were not related to distance from the smelter.

4.2.3 Long Range Transport

The concentrations of nickel and copper in soils appear to be greater than background levels for at least 40 km from the smelter in the south-east direction (Section 5.2.3.2). Since the prevailing winds are from the north-west, the distances at which detectable accumulations have occurred in other directions are probably slightly less.

TABLE 4.2.1

MEAN MONTHLY DUSTFALL IN THE THOMPSON AREA, 1975 - 1980¹Tons/km²/month $\pm$ S.D.

Distance from Smelter (km)	No. of Sites	1975	1976	1977	1978	1979	1980	Mean
1.9 - 4.5	17	.38 $\pm$.42	.22 $\pm$.18	.20 $\pm$.19	.15 $\pm$.13	.14 $\pm$.10	.19 $\pm$.15	.21 $\pm$.17
6.8 - 7.8	5	.29 $\pm$.11	.20 $\pm$.12	.18 $\pm$.08	.13 $\pm$.05	.12 $\pm$.07	.17 $\pm$.09	.18 $\pm$.07
13 - 18	2-3	.07 $\pm$.04	.05 $\pm$.03	.05 $\pm$.04	.04 $\pm$.01	.04 $\pm$.02	.05 $\pm$.01	.06 $\pm$.03
60	1	-	-	-	-	.08	-	.08

¹ Derived from Ref. M14

TABLE 4.2.2

NICKEL AND COPPER CONCENTRATIONS IN MOSS TRAPS IN THE THOMPSON AREA, 1980

		µg/g ¹											
Distance from smelter (km) Direction from smelter		1.5 SW	2.3 S	4.0 SW	4.3 W	9.0 SE	11.0 S	12.2 SW	15.7 SE	18.0 NE	21.8 SE	31.8 SW	66 SW
Month		Nickel											
May		62.4	68.3	14.0	19.6	6.1	2.2	3.7	2.0	0.9	0.8	5.8	1.7
June		24.3	26.0	7.2	11.0	7.8	2.0	3.2	1.3	0.7	0.9	5.6	0.5
July		51.0	73.7	5.1	8.1	7.2	3.6	1.9	1.1	0.4	0.6	5.6	0.1
August		38.6	26.6	6.5	4.4	2.7	3.5	1.9	1.1	0.1	0.8	5.1	0.8
September		34.5	23.9	5.8	9.8	6.3	3.5	3.4	1.4	0.7	0.9	1.9	0.4
		Copper											
May		66.7	79.7	11.7	17.7	4.7	1.5	1.5	1.2	0.7	0.2	0.7	1.2
June		21.6	15.8	2.5	4.4	3.0	0.6	0.6	0.4	0.1	0.2	0.6	0.4
July		18.2	32.4	2.7	3.4	2.1	1.0	1.1	0.2	-	3.0	0.7	2.3
August		27.7	13.6	3.1	2.0	0.3	0.5	0.5	0.2	0.2	0.1	3.9	0.1
September		23.8	34.4	16.2	18.5	46.6	12.6	34.6	9.1	26.1	12.7	22.1	43.7

¹ From Ref. M19

TABLE 4.2.3

HEAVY METAL CONCENTRATIONS IN SNOW SAMPLES
FROM THE THOMPSON AREA, 1979-1981¹

Distance (km) and Direction from smelter	mg/L									
	Ni			Cu			Pb			As
	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979
1.5 SW	-	5.00	.74	-	7.65	1.33	-	.03	.01	-
2.3 S	-	1.10	.64	-	1.20	.67	-	≤.03	.01	-
4.0 SW	.01	.44	.06	.06	.34	.07	.04	≤.03	.01	.010
4.3 W	-	.28	-	-	.22	-	-	≤.03	-	-
9.0 SE	.03	.24	.08	.45	.09	.07	.02	≤.03	.01	.005
11.0 S	.005	.18	.04	.04	.05	.02	.005	≤.03	.01	.001
12.2 SW	.005	.20	.02	.034	.06	.02	.02	≤.03	.01	.001
15.7 SE	.025	.10	.02	.025	.03	.02	.02	≤.03	.01	.002
18.0 NE	-	-	.02	-	-	.01	-	-	.01	-
21.8 SE	≤.005	.08	.02	.02	.03	.02	.005	≤.03	.02	≤.001
31.8 SW	.005	.05	.02	.055	.02	.01	.025	≤.03	.01	.001
66 SW	≤.005	≤.03	.02	.025	≤.01	.01	.005	≤.03	.01	≤.001

¹ From Ref. M19

4.3 Hudson Bay Mining and Smelting - Flin Flon

4.3.1 Local Ambient Air Concentrations

No data were available on concentrations of heavy metals in ambient air. However, based on stack particulate composition, zinc is expected to be the principal contaminant. Compliance tests conducted during September, 1982 showed that metals comprised the following percentages of the particulates: Zn - 21.7%, Pb - 7.5%, Fe - 2.7%, As - 2.3%, Cu - 2.3%, Cd - 1.0%, Cr - 0.17%, Ni - 0.08%, Co - 0.004% (Clean Environment Commission, 1983 - Ref M1).

4.3.2 Local Deposition Rates

During 1982, the installation of a new electrostatic precipitator on the zinc process resulted in major reductions in the emissions of zinc and other heavy metals. Studies on atmospheric deposition carried out prior to 1982, (Franzin et al, 1979 - Ref. M15; Franzin and McFarlane, 1981 - Ref. M12), are therefore not applicable to the present situation and are not discussed. However, Phillips et al, (1983 - Ref. M23) describe snow chemistry during the years 1981-1983. These data represent the only information found on current deposition rates and also show the decrease in these rates as a result of the new precipitator.

Mean accumulations of zinc, copper, lead and cadmium in snow at distances of 5-38 km from the smelter during 1981, 1982 and 1983 are shown in Tables 4.3.1 - 4.3.4. Maximum levels of these metals in 1981 and 1983 show a considerable reduction in deposition rates (in mg/m²): Zn (5393,129); Cu (162,19); Pb (82,5); Cd (2.5, 0.8). With the exception of cadmium, the accumulations of these metals decrease with distance from the smelter but levels still appear to be slightly greater than background 38 km away. Figure 4.3.1 shows the typical pattern of decline for these metals. Cadmium accumulations do not appear to be greatly above background, even near the smelter. Similar data for arsenic were not available.

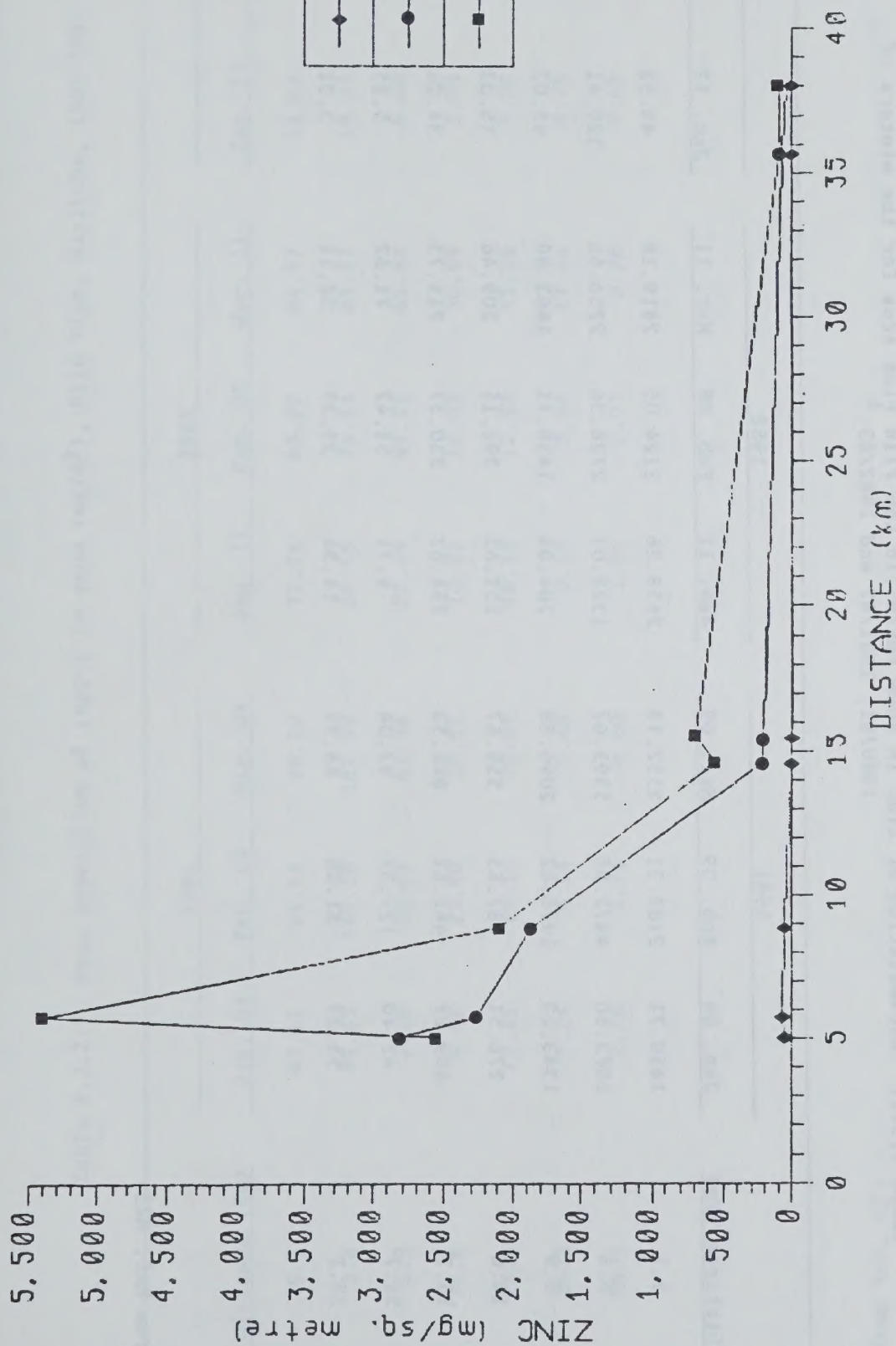


FIGURE 4.3.1 ZINC IN SNOW, FLIN FLON, MANITOBA, 1981-1983

SOURCE: REF. M23

Table 4.3.1: Accumulation of zinc in snow (mg/m²) in the Flin Flon area for the winters of 1980/81, 1981/82 and 1982/83.

Site	Distance (Km)	1981			1982			1983		
		Jan. 04	Feb. 09	Mar. 09	Jan. 11	Feb. 08	Mar. 11	Jan. 12		Mar. 09
1	5.1	1450.71	2188.31	2552.13	2658.26	2124.05	2819.18	49.93		55.66
5	5.8	3083.60	4472.86	5393.67	1322.07	2726.36	2256.66	129.41		83.50
2	8.9	1343.10	1976.42	2096.88	704.04	1438.71	1863.89	95.07		54.80
6	14.6	276.51	567.65	559.67	152.63	392.15	209.46	15.03		11.53
3	15.5	409.22	441.62	686.53	254.62	330.37	215.73	34.24		13.21
7	35.7	42.40	127.37	97.04	9.71	51.42	71.62	5.25		10.05
4	38.1	55.39	81.06	84.99	14.36	39.39	38.11	3.31		4.24

1. from Ref. M23

Table 4.3.2: Mean Deposition of copper to snow (mg/m²), Flin Flon, Manitoba, 1981-1983¹

Site	Distance (Km)	1981			1982			1983	
		Jan. 04	Feb. 09	Mar. 09	Jan. 11	Feb. 08	Mar. 11	Jan. 12	Mar. 09
1	5.1	47.11	84.14	98.10	71.14	63.29	94.57	11.93	19.07
5	5.8	99.65	149.18	162.69	38.56	76.14	83.77	13.47	11.87
2	8.9	2.29	66.41	67.94	21.49	47.21	65.82	6.48	7.13
6	14.6	9.48	23.60	19.61	10.33	14.05	30.99	2.89	2.53
3	15.5	12.35	15.30	18.01	10.19	12.58	13.34	4.20	2.36
7	35.7	2.14	8.14	5.49	0.55	3.44	17.34	0.76	1.98
4	38.1	2.74	4.74	4.60	1.01	2.03	3.26	0.49	0.70

1. from Ref. M23

Table 4.3.3: Mean Deposition of lead to snow (mg/m²), Flin Flon, Manitoba, 1981-1983¹

Site	Distance (Km)	1981			1982			1983	
		Jan. 04	Feb. 09	Mar. 09	Jan. 11	Feb. 08	Mar. 11	Jan. 12	Mar. 09
1	5.1	25.91	42.48	45.17	40.66	40.60	47.80	1.95	3.59
5	5.8	55.10	72.99	82.20	19.90	38.47	33.12	4.43	4.89
2	8.9	25.07	36.32	36.21	12.43	30.72	36.66	3.54	2.75
6	14.6	5.94	16.32	18.02	5.39	9.23	11.30	1.15	1.12
3	15.5	10.12	12.50	15.57	7.61	8.22	7.52	1.82	1.12
7	35.7	2.06	7.56	6.37	1.10	2.86	5.56	0.64	1.00
4	38.1	1.88	5.29	5.43	1.01	2.03	2.61	0.43	0.64

1. from Ref. M23

Table 4.3.4: Mean Deposition of cadmium to snow (mg/m²), Flin Flon, Manitoba, 1981-1983¹

Site	Distance (Km)	1981			1982			1983	
		Jan. 04	Feb. 09	Mar. 09	Jan. 11	Feb. 08	Mar. 11	Jan. 12	Mar. 09
1	5.1	1.65	1.36	0.58	4.39	5.35	8.33	0.33	0.26
5	5.8	1.18	1.15	0.34	4.16	4.69	4.39	0.85	0.40
2	8.9	2.24	1.86	1.25	2.72	3.90	4.71	0.76	0.26
6	14.6	1.05	2.49	1.34	0.81	1.80	2.01	<0.29	0.22
3	15.5	1.47	1.94	1.37	1.52	0.97	0.97	0.40	0.22
7	35.7	<0.25	1.14	0.48	0.27	0.46	0.93	<0.33	0.50
4	38.1	0.24	0.74	0.42	0.25	0.47	0.65	<0.20	0.35

1. from Ref. M23

4.3.3 Long Range Transport

Accumulations of heavy metals in soil and snow have been detected to about 40 km south-east of the smelter (prevailing winds are from the north-west), but this appears to be about the limit for significant rates of deposition. Rates of deposition were greatly reduced after 1982.

4.4 Noranda-Horne

4.4.1 Local Ambient Air Concentrations

Ambient air quality studies at Horne have concentrated on SO₂ emissions and there has apparently been very little investigation of heavy metal contamination. Further, the detailed results were not presented in the only available publication (BEST, 1979 - Ref. Q8).

Geometric mean annual concentrations of suspended particulates at five sampling stations within or very close to Rouyn-Noranda ranged from 32-44 µg/m³ during 1976 and 1977 (Ref. Q8). Data from more distant locations were not available.

Geometric mean monthly concentrations of lead in ambient air at two locations in Rouyn-Noranda ranged from 0.11-0.80 µg/m³. The maximum daily concentration was 5.9 µg/m³. However, insufficient information was provided to assess whether or not these values were representative of typical levels in the urban area. The sampling stations for example were elevated above street level. No other data on heavy metals were available, although it is known that accumulations of copper, zinc, arsenic and cadmium have occurred in nearby soils and in snow and that mercury is also emitted from the smelter operation.

4.4.2 Local Deposition Rates

The only data concerning deposition of heavy metals which were available for this study consisted of concentrations in snow during 1976 and 1978 (BEST, 1979 - Ref. Q13). The most extensive data set was from April 1978 and this is summarized in Table 4.4.1. The data in this table should be used with caution since they were extracted from graphic representations in which concentrations at specific stations were given as ranges (eg., 0-50, 50-100, etc.); raw data were not available. However, the table is sufficiently accurate to describe general trends.

Lead concentrations in snow were very high within 10 km of the smelter (max. 8440 µg/L) and the concentrations of zinc, copper, cadmium and arsenic were also high, particularly within 5 km of the smelter (max. µg/L: Zn-608; Cu-3280; Cd-88; As-540). Other surveys (Ref. Q13) have shown zinc and cadmium concentrations to reach 6800 and 152 µg/L respectively. Although regional background concentrations of these metals were not provided, it appears that smelter emissions have increased deposition rates for at least 15 km from the smelter. There was a general trend for concentrations to be higher to the south-east of the smelter (prevailing winds are north-west).

In contrast to the other metals, the deposition rate for mercury was directly related to distance from the smelter. The median mercury concentration 15-30 km away was in the range of 0.30-0.39 µg/L whereas the highest value within 2 km of the smelter was 0.12 µg/L or less.

4.4.3 Long Range Transport

It is apparent that mercury emissions may be transported for a considerable distance before being deposited. The sampling network would have to be extended much farther to allow the zone of influence of the smelter to be assessed.

TABLE 4.4.1

MEAN, MEDIAN AND RANGE OF CONCENTRATIONS
OF HEAVY METALS IN SNOW IN THE
ROUYN-NORANDA AREA, APRIL 1978¹

Distance from smelter (km)	Number of Stations	$\mu\text{g/L}$					
		Zn	Cu	Cd	Pb	As	Hg
1-2	5	51-608* ²	201-3280*	5-88	61-8440	50-540*	<.05-.12
		265 ³	1860	31	3180	280	.07
		101-200 ⁴	501-3280	5-40	1001-3000	151-300	.05-.12
2-5	9	51-500	101-3280	5-88*	1001-8440	50-540	<.05-.39
		260	650	37	2860	190	.11
		201-500	201-500	5-40	1001-3000	151-300	.05-.12
5-10	16-17	<50-500	6-500	5-88	61-8440*	<50-540	<.05-1.54
		100	90	19	1180	84	.13
		51-100	6-50	5-40	301-1000	<50	.05
10-15	14	<50-200	6-100	0.5-40	51-3000	<50-150	<.05-1.54
		45	30	5	320	36	0.25
		<50	6-50	0.5-4	61-300	<50	.05-.12
15-30	9	<50-100	<5-50	<0.4-4	31-300	<50	<.05-1.54
		30	20	2	150	<50	0.57
		<50	6-50	0.5-4	61-300	<50	.30-.39

¹ derived from Ref. Q13, Figures 14.2, 14.4, 14.6, 14.8, 14.10, 14.12

² range; note that Ref. Q13 gave concentrations at individual stations as being within a range category (raw data not provided); actual minimum and maximum values may therefore be greater or less, respectively, than shown, except where indicated by an asterisk (*) (max. value only).

³ mean; these values have been estimated by using the mid-points of range categories.

⁴ median.

It is probable that deposition of other metals is noticeably greater than background levels primarily within 30 km of the smelter. Lead, however, may be an exception due to the very high concentrations near the source.

4.5 Noranda-Murdochville

No information was available to describe air quality in the vicinity of the Murdochville smelter.

4.6 Brunswick Mining and Smelting - Belledune

4.6.1 Local Ambient Air Concentrations

No measurements of heavy metal concentrations in ambient air were available however lead, cadmium, arsenic, copper and zinc all occur in stack emissions. During 1982, the following quantities of metals were released to the atmosphere in particulates: Pb - 47.5 t; Cd - 3.7 t; As - 3.1 t (Table 3.1.8-3). Similar data for other metals were not available.

4.6.2 Local Deposition Rates

Deposition rates have been determined, using dustfall jars, for dust and lead in dust at distances up to 38 km from the smelter (Table 4.6.1). Lead deposition is noticeably high only within 1 km of the smelter (max. in 1980 - 70 mg/m²/month) and appears to be near background levels at greater distances. The reason for the decline in lead deposition between 1976 and 1979 (see Table 4.6.1) is not known. No data were found concerning wet deposition or deposition of other metals.

TABLE 4.6.1

DUSTFALL AND LEAD IN DUSTFALL IN THE BELLEDUNE AREA¹

Distance from stack (km)	Number of Sampling Sites	Dustfall (g/m ²)month						Lead in Dustfall (mg/m ² /month)					
		1973	1974	1975	1976	1979	1980	1973	1974	1975	1976	1979	1980
0 - 0.8	5	5.7	8.2	5.4	3.6	3.6	2.9	260	800	450	320	90	70
0.9 - 1.6	4	1.7	1.9	1.5	1.7	1.5	1.8	50	70	50	50	35	20
1.7 - 3.2	4	1.2	2.1	1.2	1.5	1.5	1.7	50	70	50	35	50	20
3.3 - 8.0	2	1.2	1.1	1.4	1.8	2.0	4.1	35	35	35	20	20	20
8.1 - 16.0	3	0.9	1.0	1.0	1.1	0.7	1.2	35	50	20	35	20	5
16.1 - 38.4	2	1.2	1.4	0.9	2.4	-	-	35	35	20	35	-	-

¹ derived from Ref. N6

4.6.3 Long Range Transport

From soil data, it appears that deposition of metals in smelter emissions has been largely confined to areas within about 8 km of the main stack. Slightly higher-than-background lead concentrations however have been detected in vegetation (forage) up to 16 km away.

4.7 Cominco-Trail

The only air quality data available for this study were contained in the Kootenay Air and Water Quality Study, Phase I (Ref. B12). These data were fairly old (1972-74) and may not be applicable to the present smelter operations.

4.7.1 Local Ambient Air Concentrations

Concentrations of lead, zinc, cadmium and arsenic in ambient air during 1973 at three stations located within 2 km of the smelter are shown in Table 4.7.1. Mean levels of all metals were below Provincial guidelines but were greater than background levels as recorded during part of 1974 when the smelter was not in operation (Table 4.7.1).

4.7.2 Local Deposition Rates

Deposition rates of heavy metals at 12 locations within 21 km of the smelter during 1972-1974 are summarized in Table 4.7.2. Mean rates were very high within 0.6 km of the smelter, especially for lead and copper (425,809 mg/m²/month respectively), but even arsenic and cadmium levels are about ten times background. However the deposition rates fall off very rapidly with increasing distance such that they were at or close to apparent background levels beyond about 9 km from the smelter.

No data were available to describe wet deposition.

4.7.3 Long Range Transport

Not enough information was available to accurately assess the distances at which smelter emissions have a measurable influence on air quality or deposition rates. Soil data usually provide the best indication since metal concentrations in soil represent long-term accumulations, but sufficiently detailed data were not available. However in general it appears that the smelter's influence was largely confined to an area of radius 10 km prior to 1975.

TABLE 4.7.1

CONCENTRATIONS OF HEAVY METALS IN AMBIENT AIR IN THE TRAIL AREA DURING 1973¹

Distance (km) and direction from smelter	Range and geometric mean ($\mu\text{g}/\text{m}^3$)			
	Pb	Zn	As	Cd
0.5 SE	0.34 - 8.5 (2.59)	0.16 - 7.09 (1.94)	0.02 - 1.44 (0.27)	0.01 - 0.51 (0.07)
1 SE	0.21 - 6.02 (2.08)	0.22 - 4.92 (1.13)	0.01 - 0.78 (0.09)	0.001 - 0.23 (0.06)
2 W	0.27 - 10.1 (1.66)	0.13 - 6.3 (1.06)	0.01 - 0.41 (0.14)	0.01 - 0.41 (0.05)
Provincial Level B Guidelines. Max. 24 hr. concentration	4.0	5.0	1.0	0.1
Background concentrations (Trail during 1974 strike)	<0.5	0.01 - 4.13 ² (0.18)	<0.02	<0.01

¹ from Ref. B12² Nelson downtown, 1974

TABLE 4.7.2

MEAN DEPOSITION OF HEAVY METALS IN DUSTFALL IN THE TRAIL AREA, 1972-74¹

Distance from smelter	Number of Sampling sites	mg/m ² /month			
		Pb	Zn	As ²	Cd ²
0 - 0.6	4	425	809	7	6.1
1 - 2	3	90	278	2	1.4
3 - 3.5	2	54	110	2	1.1
8 - 9	2	17	30	1	0.5
21	1	14	20	1	0.5

¹ derived from Ref. B12 (Table C-34)² 1972 and 1974 only.

5.0 EFFECTS OF SMELTER EMISSIONS

5.1 Human Health Effects

Introduction

The objective of this section of the study dealing with human health effects was to assemble available information on the observed/measured health effects of local deposition ambient air concentrations and long range transported heavy metal emissions from Inco (Sudbury), Inco (Thompson), Falconbridge (Sudbury), Hudson's Bay Mining and Smelting (Flin Flon), Noranda (Horne), Noranda (Murdochville), Brunswick Mining and Smelting (Belledune) and Cominco (Trail).

The heavy metals of primary concern are lead, mercury, arsenic and cadmium. Heavy metals of secondary concern included zinc, nickel, copper and selenium and also cobalt. Cobalt is associated primarily with three smelter operations as a minor constituent, Inco (Sudbury and Thompson) and Falconbridge (Sudbury).

The health effects review is included in Section 5.1.2. Information gaps in the health effects review are identified in Section 6.2.

A secondary objective was to provide a brief summary of the adverse health effects associated with each of the metals identified. Available information regarding the type of metals, occupational and public health effects, as well as possible effects of interactions with other contaminants, are considered.

The principal factors that should be considered in the overall assessment of the human health effects of smelter emissions are included in Section 5.1.1.

5.1.1 Review of Health Effects of Heavy Metals

Lead

Forms of lead which have recognized health effects include metallic lead, lead arsenate, lead chromate, lead nitrate, lead sulphate, lead oxide, lead sulfide, lead acetate, lead chlorate, lead chloride, tetraethyl lead (TEL) and tetramethyl lead (TML).

Lead may be absorbed in the body through inhalation, ingestion (food or drink), and by the placenta. Ingestion is a significant route for children. Alkyl leads (TEL, TML) can be absorbed through the skin.

Lead produces adverse effects on hemoglobin synthesis and chronic exposure can result in anemia in adults and children. Encephalopathy and behavioural abnormalities are also common in children poisoned with lead. The most common type of acute lead poisoning is gastrointestinal. Long-term exposure may produce reversible and morphological changes in the kidney in adults and the central nervous system in children resulting in behavioural abnormalities.

There is no conclusive evidence of carcinogenicity from lead exposure in humans but benign and malignant tumours have been reported in lab animals exposed to lead (Ref. G65).

Epidemiological data from women working in environments high in lead and arsenic plus other undefined materials showed increased incidences of spontaneous abortions and cleft palate and decreased birth weight of offspring (Ref. G66).

In one study, workers exposed to lead and displaying signs of lead poisoning showed an increased incidence of chromosomal aberrations (Ref. G67).

In two mortality studies, there were an excess of deaths by "cerebrovasculaires" in workers occupationally exposed to lead (Ref. G41, G42). Other more recent mortality studies in lead workers have not confirmed these findings, but have found a slight increase in deaths due to chronic kidney problems, gastro-intestinal cancer and lung cancer (Reg. G43, G44).

With respect to exposure of the general population to levels emitted from nearby smelters, one study reported the presence of anemia and decreased nerve conduction in children near a lead smelter (Ref. G45), while another found elevated lung cancer rates in the population near a copper/lead/zinc smelter and refinery (Ref. G46).

In the mortality study of Rouyn-Noranda residents, BEST (Ref. Q1), concluded that lead emissions from the copper smelter could possibly be a contributing factor to excess lung cancers in men over 20 (including and excluding ex-smelter workers); arsenic emissions were suspected as the principal factor.

Lead arsenate produces a double hazard in that it can produce either lead or arsenic intoxication. Acute toxicity is due chiefly to arsenic, while the chronic effects are likely to be those of lead poisoning (Ref. G68).

The health hazard presented by lead chromate is that the chromium constituent is a suspected human carcinogen.

Accidental or occupational exposure to alkyl lead compounds can result in acute encephalopathy.

Lead may interact with other metals. Lead and cadmium seem to be synergistic in experimental teratogenesis (Ref. G69), whereas zinc appears to be antagonistic to lead (Ref. G70, G71).

Mercury

Forms of mercury which have recognized health effects include mercury liquid, mercury vapour, mercuric halide, mercuric sulfates, mercuric nitrates, mercuric cyanide, mercuric acetate, mercuric oxides, alkylmercury compounds, alkoxyalkylmercury compounds and phenylmercury compounds.

Mercury may enter the body through inhalation, ingestion (food or drink), especially alkylmercury (fish), and likely through the skin to a small extent. Mercury vapour, in contrast to mercuric mercury also penetrates the placental barrier. Mercury poisoning in humans is associated primarily with accidental industrial exposures or ingestion of contaminated food (Ref. G75).

Inorganic and organic mercury compounds all have different toxicological properties. Acute poisoning by inhalation of high levels of mercury vapour can cause erosive bronchitis and cause liver and kidney damage. Chronic exposure to toxic levels affects the central nervous system primarily and includes micromercurialism and mercurial erethism.

Regarding mercuric mercury, acute poisoning from ingestion of sublimate or mercuric salts damages the kidney and intestinal tract. Chronic poisoning involving exposure to mercury vapour and mercuric mercury may cause renal damage.

Methyl mercury has similar toxicological effects to ethyl mercury. Both are considered as relatively stable in the mammalian body, and show greater toxicity than inorganic mercury compounds. The primary areas of concern are the neurotoxic effects (motor and sensory nerves primarily) embryotoxic effects and genetic effects (chromosomal aberrations).

Severe exposure can produce permanent impairment of speech, vision, hearing, sensory loss in the limbs or death.

Organic compounds that are considered unstable in the mammalian body include the phenylmercury and alkoxyalkylmercury compounds. Acute inhalation exposures can result in local damage in the lung, renal damage and intestinal complaints (Ref. G72).

Inorganic and aryl mercury compounds are considered less toxic than elemental mercury vapour and alkyl mercury since apparently less mercury is deposited in the brain following absorption (Ref. G73, G74).

Incidences of mercury poisoning have been documented in the 1950's in Minamata, Japan (contaminated shellfish from methylmercury, discharge of a vinyl chloride and acetaldehyde plant), in 1971-72 in Iraq (methylmercury treated grain) and recently in several reservations in Ontario and Quebec (contaminated fish).

A study investigating mercury in the Swedish environment (Ref. G76) reported that around a large smelter, mercury levels in lake sediments were significantly increased even greater than 50 km from the plant.

Arsenic

Forms of arsenic which have recognized health effects include metallic arsenic, arsenic trioxide, arsine, arsenic trichloride, arsenic pentoxide, arsenic selenide, arsenic pentasulfide, cadmium arsenate, copper aceto-arsenite, calcium arsenate, lead, arsenate sodium, arsenite, arsenic trifluoride, arsenate, methylarsenes, arsones, dimethylarsinic acid, cacodylic acid, copper aceto-arsenite and arsenilic acid.

Arsenic may enter the body through inhalation, ingestion (food or drink), or through the skin.

Acute arsenic poisoning in humans, usually by accidental, homicidal or suicidal ingestion, may cause vomiting, abdominal pain and death. Acute occupational arsine poisoning has resulted in jaundice and hemolytic anemia. Inhalation of arsenic trioxide and arsenic trichloride can cause severe damage to the respiratory system. Chronic exposure to arsenic and its compounds among industrial workers has resulted in various symptoms including skin dermatitis, conjunctivitis associated with facial dermatitis, corneal ulceration from calcium arsenate exposure, perforation of the nasal septum, gastroenteritis, peripheral neuropathy characterized by motor dysfunction and paresthesia, liver cirrhosis, and anemia.

The toxicities of arsenic compounds, in particular, the acute toxicities, are related to their solubility in water. Thus most arsenates and arsenites are regarded as acute poisons, while sulfides are less toxic in an acute sense but may be equally hazardous from a chronic sense (Ref. G68).

Occupational exposure studies have found excess mortality from respiratory cancer and heart disease, with positive correlation between length of exposure and respiratory cancer (Ref. G48, G49, G50). In a recent study conducted in Sweden, excess respiratory cancers, "leukaemia" and liver cirrhosis were found in copper refinery workers (Ref. G51). Skin cancer from arsenic exposure has been documented (Ref. G68).

Both trivalent arsenic compounds such as arsenic trioxide and pentavalent forms such as lead and calcium arsenates have been found to cause cancer in the lung, lymphatic system and skin (Ref. G78).

Studies of populations living near smelters have demonstrated elevated levels of arsenic in urine and hair of children, with levels being a function of vicinity to the smelter and location with respect to prevailing

winds (Ref. G52, G53, G54). Excess lung cancers in residents have been associated with arsenic levels in locations where smelters are present (Ref. G46, G55, G52, G83, G84).

Several researchers have hypothesized that SO_2 is a co-carcinogen and when associated with arsenic trioxide causes lung cancer, both in an occupational and non-occupational environment (Ref. G46, G48, G68).

In their mortality study of Rouyn-Noranda residents, BEST (Ref. Q1) concluded that arsenic emissions from the copper smelter were suspected as being the main cause in excess lung cancers in men over 20 (including and excluding ex-smelter workers). Sulphur dioxide emissions, as well as lead, cadmium and zinc were suspected as contributing factors. This is supported by another study (Ref. G77) which recognized that respiratory cancer in smelter workers may be promoted by concurrent exposures to sulphur dioxide, silica and metals like antimony and lead.

In one study, nervous disorders in the form of abnormal electromyograms were reported among people who had lived near an arsenic mine and smelter and who did not show subjective symptoms (Ref. G79).

Arsenic may interact with other metals. Arsenic and lead appear to be additive in experimental animals in terms of effects on functional changes in the central nervous system (Ref. G80). Arsenical interactions with selenium (Ref. G81) and with lead or cadmium (Ref. G82) have also been described.

Cadmium

Forms of cadmium which have recognized health effects include metallic cadmium, cadmium acetate, cadmium sulfide, cadmium sulfoselenide, cadmium cyanide, cadmium oxide, cadmium carbonate, cadmium sulfate, cadmium chloride, cadmium hydroxide, cadmium nitrate, cadmium selenide, cadmium telluride, diethyl cadmium and copper-cadmium alloys.

Cadmium may be absorbed in the body through inhalation or ingestion (food or drink). Ingestion is a significant route for children.

Inhalation of cadmium affects the respiratory system, cardiovascular system and the excretory system of humans and animals. The result of acute poisoning from inhalation overexposure to heated cadmium may be severe tracheo-bronchitis, pneumonitis and pulmonary edema (Ref. G113, G86).

Chronic cadmium poisoning through inhalation of cadmium dusts, salts and fumes results in pulmonary emphysema and later bronchitis with or without renal tubular injury and bone changes.

Information on teratogenicity is limited. Cadmium sulfate has been reported as a teratogen to hamster embryos. Female rats produced smaller offspring under low concentration exposure. High concentration exposure resulted in dose-related fetal deaths, decreased fetal weight and increased fetal anomalies (Ref. G113, G86).

It has been reported that human placental barriers are effective against cadmium such that the newborn is practically free of cadmium (Ref. G103).

Past animal studies have implicated various cadmium compounds (CdCl_2 , CdS , CdSO_4 and metallic Cd) as carcinogens resulting in rhabdomyosarcomas and testicular tumors, but there are no reports that cadmium is carcinogenic by ingestion, and no attempts have been made to show carcinogenicity by inhalation.

Regarding occupational exposures, in 1965, 3 deaths out of 74 workers, who were exposed for more than 10 years to cadmium oxide dust in alkaline cadmium battery manufacturing were reportedly caused by carcinoma of the prostate, carcinoma of the bronchus, and the third by carcinomatosis. Further investigations revealed high incidences of prostatic and bronchial carcinomas among workers exposed to cadmium oxide dust. A preliminary

report of a cancer-mortality study of cadmium production workers revealed increased incidence of lung and prostate cancer. From a cohort of 283 cadmium smelter workers exposed for more than 3 years, there was increased incidence of malignant neoplasms of all types, increased incidence of deaths from malignant respiratory disease and increased cases of prostatic cancer. Although it is likely that cadmium is a human carcinogen, the evidence is not decisive (Ref. G68, Q1).

Two cases of fatal emphysema were reported in workers making copper-cadmium alloy. Emphysema and proteinuria cases were reported in workers engaged in copper-cadmium alloy casting (Ref. G68).

Cadmium interaction with several metals appears to be important in cadmium toxicity. Cadmium-induced acute testicular necrosis can be prevented by administration of zinc, cobalt, or selenium. Hypertension caused by cadmium in rats may be reversed by administration of zinc chelates (Ref. G113, G86).

BEST (Ref. Q1) found in its study of the Rouyn-Noranda copper smelter that although excess cardio-vascular disease in Rouyn-Noranda men between 45 and 64 (excluding ex-workers from the smelter) was observed, and could perhaps be associated with the presence of cadmium emissions from the smelter, there was reason to doubt the relation since several other population groups did not show excess cardio-vascular disease, as might be expected. Cadmium emissions were, however suspected as contributing to the excess lung cancers in men over 20 (including and excluding ex-smelter workers); arsenic emissions were suspected as the principal factor.

Zinc

Forms of zinc which have recognized health effects include zinc chloride, zinc chromates, zinc oxide, zinc stearate, zinc nitrate, zinc sulphate, zinc phosphate, zinc carbamate, and zinc ammonium sulfate.

Zinc may be absorbed in the body through inhalation and ingestion (food and drink). Zinc is an essential metal, necessary for the function of various mammalian enzymes.

Exposure to zinc chloride fumes greater than a concentration of 15 mg/m³ may result in severe respiratory tract effects, pneumonitis and fatal pulmonary edema. Damage occurs to the mucous membranes of the nasopharynx and respiratory tract (Ref. G68).

Zinc chromate is a suspected carcinogen in humans. Possible carcinogenic effects associated with exposure to zinc chromate is likely due to the presence of the chromate ion rather than the zinc component.

Toxicity of zinc compounds by ingestion is low but has been associated with gastrointestinal disturbances (Ref. G87). Inhalation of relatively high concentrations of zinc oxide fumes may cause metal fume fever (zinc chills, brass founder's ague, etc.). Symptoms may include headache, fever and chills and complete recovery occurs within 48 hours.

Large oral doses of zinc salts (such as nitrate and sulfate) produce gastrointestinal disorders, vomiting and diarrhea but chronic toxic effects of most zinc salts have not been observed in humans.

Zinc stearate is a nuisance particulate, used in the rubber industry as a dusting and mold-release agent or lubricant and has not generally been associated with adverse effects.

For zinc chloride, zinc nitrate and zinc sulfate, there has been no evidence of carcinogenicity in human populations available (Ref. G89). The IARC (Ref. G90) evaluation does list zinc chromate as a positive human carcinogen.

Zinc is regarded as fetotoxic but not teratogenic (Ref. G88).

Although one study found a positive correlation between ambient levels of zinc in 28 U.S. cities and number of illnesses involving cardio-vascular and hypertensive problems in the cities (Reg. G47), this study was considered as being inconclusive (Ref. Q1).

BEST (Ref. Q1) found in its study of the Rouyn-Noranda copper smelter that although excess cardio-vascular disease in Rouyn-Noranda men between 45 and 64 (excluding ex-workers from the smelter) was observed, and could perhaps be associated with the presence of zinc emissions from the smelter, there was reason to doubt the relation since several other population groups did not show excess cardio-vascular disease, as might be expected.

Zinc deficiencies have been associated with developmental abnormalities in laboratory rodents and abnormal deliveries in women (Ref. G67).

Cadmium administration in zinc deficient rats increases the effects of zinc deficiency. Cadmium is known to replace zinc in some metabolic processes (Ref. G103).

Copper

Forms of copper which have recognized health effects include elemental copper, copper sulfate, copper acetate, copper carbonate, copper cyanide, copper oxide, copper sulfide, copper chloride, copper stearate, various sulfide ores (eg. chalcocite), various oxidized ores (eg. cuprite), and many alloys such as brass and bronze.

Copper can be absorbed in the body through inhalation and ingestion (food or drink). Copper is an essential metal and forms an essential part of several enzymes.

Industrial exposure to copper dust or fumes causes acute irritation in the upper respiratory tract, a metallic or sweet taste, nausea, metal fume fever, and sometimes discoloration of skin and hair. Metal fume fever is an influenza-like syndrome with symptoms disappearing after 24 hours. Investigations seeking to link copper dust or fumes in industry as capable of causing chronic lung damage, have been negative (Ref. G104). At higher concentrations, inhalation causes congestion of nasal mucous membranes, sometimes of the pharynx, and sometimes ulceration of the nasal septum.

Copper metal dust is the most toxic; the most toxic of the copper salts are the sulfate and chloride. Large ingested amounts produce gastrointestinal disturbances, hemolysis, liver damage and renal damage. There are a surprising number of cases of ingestion of copper sulfate with various results, including vomiting and diarrhea, blood in the gastrointestinal tract, injury to the gastric mucosa (sometimes ulceration), jaundice, suppression of urine, hypertension leading to shock and death, and coma.

Swedish workers handling copper sheeting reported similar responses from chronic exposure to dusts of mixed copper salts, basic copper nitrate and sulfate, copper silicate and copper oxide. Anemia may occur. Copper salts on the skin produce act as irritants, producing eczema. Six cases of allergic contact dermatitis were reported up to 1972 (Ref. G68).

Vineyard workers spraying vines with copper sulfate solutions reported lung changes, liver fibrosis, cirrhosis and angiosarcoma (Ref. G91).

Human data reveals that copper does not produce teratogenic effects. Copper smelting operations may contain certain environments that contain materials causing increased spontaneous abortions in women but they could not be attributed solely to copper.

Fetal mortality among wives of copper smelter workers in Sweden was studied (Ref. G92). The rate of congenital abnormalities was not significantly different between the control group and the wives of smelter workers. There was a slight increase in spontaneous abortions in the exposed pregnancy group.

Insufficient data was available to assess the carcinogenicity of copper.

Urinary excretion and copper metabolism is influenced by molybdenum intake in humans. Low molybdenum concentration in the diet results in low excretion of copper. Copper deficiency may occur where molybdenum intake is excessive.

Selenium

Forms of selenium which have recognized health effects include elemental selenium, selenium oxychloride, selenium oxide, selenium dioxide, selenium hexafluoride, selenium halide, selenium sulfide, methylselenide, hydrogen selenide, cadmium selenide, ferric selenite, sodium selenite, selenates, selenopersulfide, selenotrisulfide, selenocystine, selenomethionine, trimethylselenium and selenium diethyldithiocarbamate.

Selenium may be absorbed in the body through inhalation and ingestion (food or drink).

Selenium is an essential trace element, and serves several cellular functions (Ref. G93).

Selenium deficiency produces many diseases in animals; however, there is no conclusive evidence of a human disease attributed to selenium deficiency. It may be associated with periodontal disease, sudden infant death syndrome and increased cancer incidence.

Acute toxicities of selenium compounds vary greatly from the highly poisonous hydrogen selenide, selenium dioxide and hexafluoride, to those of the element and sulfides (often considered non-toxic). Chronic effects of almost all forms of selenium are similar. There have been no reports of disabling chronic disease or death from industrial exposures (Ref. G94). However, Rosenfeld (Ref. G95) states that long-term exposure to selenium can possibly lead to kidney and liver damage. Continuous exposure to selenium dust and gases in the air may lead to lung fibrosis.

Selenosis or selenium accumulation has been associated with loss of hair, nails and teeth, epidermal malformations, chronic dermatitis, and progressive paralysis (Ref. G20). The degree of illness depends on the amount, method, duration and chemical form of the exposure and also the presence of other chemicals.

Heated selenium produces selenium dioxide, the primary problem of industrial exposure and can cause conjunctivitis, sore throat and dyspnea (Ref. G102). Selenium dioxide forms selenious acid upon contact with water or sweat. This acid acts as an irritant.

Occupational exposure to selenium oxide has resulted in bronchial spasms, asphyxiation and chemical pneumonia, with full recovery shortly after.

Acute industrial exposure to elemental selenium by heavily exposed workers resulted in mucous membrane irritation, difficulty in breathing, dyspnea and some dermatitis (Ref. G85).

Hydrogen selenide is highly toxic, acidic and irritating (Ref. G96, G97). Results of acute hydrogen selenide inhalation include irritation of the respiratory tract mucous membranes, pulmonary edema, severe bronchitis, and bronchial pneumonia.

Accidental exposure of female lab workers to selenite resulted in the termination of several pregnancies by miscarriages and one bilateral club foot infant (Ref. G85). Oral ingestion of pure selenium is harmless while selenium compounds are dangerous; organic compounds are more harmful than inorganic compounds (Ref. G98).

There is considerable controversy concerning selenium's relationship to cancer. It has been accused of causing cancer and praised for preventing cancer (Ref. G20). Two hundred rats were fed selenate to determine carcinogenic potential. Some developed sarcomas, hepatic carcinomas and hepatic adenomas. However, U.S. governmental authorities have accepted that selenium feed additives pose no carcinogenic hazard to man (Ref. G85).

Arsenic is antagonistic to many of the toxic effects of selenium causing vascular damage. This has been reported in animal studies (Ref. G20). Dietary sulfate, arsenic, linseed meal and methionine have been regarded as partially protecting against selenium poisoning (Ref. G20).

Nickel

Forms of nickel which have recognized health effects include elemental nickel, nickel sulfide, nickel oxide, nickel carbonyl, ferronickel, nickel silicate, nickel sulfate, nickel chloride, nickel fluoride, nickel formate, nickel hydroxide, nickel iodide, nickel nitrates, nickel monoxide, nickel oxalate, nickel phosphate, nickel potassium sulfate, nickel selenate, nickel selenite, nickel selenide, nickel acetate, nickel arsenate, nickel cyanide, cyclopenta-dienyl-nickel carbonyl, dicyclopentadiene nickel, special alloys for addition to cast iron and stainless steel.

Nickel may enter the body through inhalation and ingestion (food or drink), and by the placenta.

Toxicity varies; the uncombined form is relatively non-toxic. Most nickel salts are highly toxic. Nickel carbonyl is extremely toxic. Large doses of ingested soluble nickel salts produce nausea, diarrhea and vomiting (drinking water is the common source). Insoluble inorganic nickel compounds have a low order of oral toxicity. Acute lethality depends upon the chemical nature of the nickel compound and its method of administration. In animal tests, large amounts of nickel metal were ingested without ill effects.

Workers involved with nickel refining are susceptible to dermatitis or sensitization reactions (ex. nickel salts). Some public handling of nickel items have been reported to have developed skin irritations.

Inhalation of nickel fumes and nickel carbonyl vapours cause respiratory problems among nickel workers involved in nickel polishing, electro-plating, nickel-cadmium battery manufacturing, welding and accidental exposures. After long exposure to nickel dust and fumes there is an increased risk of lung and nasal cancer. A causal relationship exists between nickel and nephritis, heart diseases, cardiovascular diseases, arteriosclerotic heart, hypertensive heart, diabetes and lung cancer. Chronic exposure to nickel fluoride may cause bone deformation and mottling of teeth.

Several epidemiological studies have been made concerning risks associated with exposures to nickel involved in the production and use of nickel metals. Lung and nasal sinus cancer has been reported in nickel workers. There existed difficulty in determining which nickel compounds were responsible since the workers may have been exposed to several simultaneously. The focus was on nickel oxide, nickel sulfide, nickel carbonyl and respirable nickel particles. Based on animal and epidemiologic studies, NIOSH concluded that all inorganic nickel compounds and nickel non-metals may be carcinogenic when airborne (recommending further investigation). Insoluble nickel compounds are associated with the greatest carcinogenic risk. Occupational exposure to nickel compounds of low solubility (especially nickel oxide and nickel subsulfide) are associated with cancer. No data

are available attributing such effects to soluble nickel compounds which are rapidly excreted from the body, thereby reducing their chance of inducing cancer (Ref. G99, G100).

In Wales, Canada, Norway and the Soviet Union, risk of developing lung and sinus cancer varied with the exposure to nickel. It is now believed that the exposure to high concentrations of nickel sulfide matte to convert it to nickel oxide was the significant exposure. This involved exposure to dust and fumes from nickel sulfide, nickel oxide, tramp elements (selenium, tellurium, arsenic, cadmium and lead), coal combustion products, sulfur dioxide and other contaminants. As a result of studies, it was revealed that no health problems arose in workers involved in processes up to the point of making crude nickel sulfide. The nickel refining processes associated with inducing cancer are calcination, smelting, roasting and electrolysis, and from nickel plating and polishing (grinding and electrolysis). Cancer of the respiratory tract was in the form of epidermoid, anaplastic and pleomorphic carcinomas. The latency period for cancer development was approximately 24 years. There is no epidemiological evidence of increased risk of respiratory cancer in any other occupational exposures with specific exposure to nickel nor in the use of lateritic ores of nickel, although there have been isolated cases attributed to nickel exposure resulting in asthma, pulmonary fibrosis and pulmonary edema due to mixed exposures of welders to oxides of nickel, ozone, fluorides, etc. The dusty sintering operations were discontinued between 1920 and 1930. Thus changes in cancer risk is related to the chronological changes in feed material and major changes in the nature of the process.

Nickel carbonyl is a gaseous compound used in the refining of nickel by the Mond process, the forming of nickel films by deposition, and as a catalyst for organic synthesis. It may be formed inadvertently when finely divided active nickel comes in contact with carbon monoxide. It can be lethal to humans, acting mainly on the lungs. Severity depends on exposure, varying from difficulty in breathing and vomiting to pneumonitis and pulmonary

damage (Ref. G67). Liver and brain injury has been reported in animals following acute exposure by inhalation and injection (Ref. G101). Nickel carbonyl is carcinogenic in laboratory animals but this has not been verified for humans.

Data on teratogenicity is inconclusive. In laboratory animals and humans, nickel is known to cross the placenta with concentrations in the maternal and fetal tissues equivalent (Ref. G99).

Cobalt

Forms of cobalt which have recognized health effects include cobaltous-chloride, -nitrate, -sulphate, -hydroxide and -carbonate; tetracarbonyl; cobaltocobaltic oxide; gray cobaltous oxide; black cobaltic oxide; cobaltosic oxide; the arsenides: smaltite, safflorite, skuterrudite and cobaltite; the sulphides: carrolite and linnaeite; and the oxides: absolite, neterogenite, sphaerocobaltite and erythrite.

Cobalt may enter the body through inhalation of cobalt metal particulates, dust or fume, ingestion (food or drink) or through the skin.

Cobalt is an essential trace element for animals and man. It is an important constituent of Vitamin B12 and certain essential enzymes (Ref. G113).

Practically all cobalt produced is a by- or coproduct of other metals, mainly copper and tellurium (Ref. G106, G113). Not only is it used in nickel plating and other metal-related processes, but also in the glass and ceramic industries as well as being an additive to livestock feeds.

Cobalt is released to the air during production of cobalt oxide and the processing of hard metals. Occupational exposure of cobalt alloy workers has led to reports of poisoning in the form of dermatitis of the allergic sensitivity type (Ref. G105). Exposure to cobalt powder, oxide or salt has

resulted in two types of respiratory disease, pneumoconiosis and lung problems. Numerous hard metal disease (pneumoconiosis) reports in Europe have been noted in the manufacturing and grinding of cobalt alloys. This disease is characterized by interstitial pneumonia with dyspnea (Ref. G113). Death has been the result of many cases. Lungs showed interstitial infiltration and fibrosis.

Carcinogenic and teratogenic data on humans is unavailable. Some rats injected with cobalt powder and salts developed sarcomata. Slight teratogenic effects were seen in chicken eggs induced by injection (Ref. G111, G112).

Iron seems to be associated with cobalt in human metabolism. An iron deficiency will increase cobalt absorption whereas simultaneous administration of iron and cobalt will decrease cobalt absorption (Ref. G110).

Human Health Effects in Perspective

The impact of non-ferrous smelter emissions on human health should ideally be considered as a function of the exposure levels (i.e. ambient levels) of all metallic and non-metallic emissions (gaseous and particulate), the population profile (including age, sex and individual sensitivities) and the various activities of the population (including occupational exposures).

Although those heavy metal emissions suspected of highest toxicity potential were reviewed in this study, both data gaps and a lack of understanding of all adverse health effects present a serious limit regarding interpretation.

Populations are commonly exposed to multiple chemical agents on the job and in the community. The health effects of these agents in complex combinations cannot, in general, be assessed. It is known that some chemicals create a greater effect in combination than acting alone (synergism), and some act in the opposite manner (antagonism).

For example, the combination effect of sulphur dioxide, suspended particulate matter, nitrogen oxides, polynuclear aromatic hydrocarbons, etc., is not clearly understood (Ref. G107), but attempts have been made to determine the impact on populations. In the Rouyn-Noranda mortality study (Ref. Q1), emissions of cadmium, lead, zinc and SO_2 were all regarded as contributing factors to excess lung cancers.

Although the total exposure of chemicals on an individual is important, there are at present few comprehensive studies available. Absorption into the body through inhalation and ingestion, for example, have been demonstrated for all eight metals studied. The U.S. EPA Carcinogen Assessment Group has calculated the effect of inhalation exposure for arsenic, cadmium and nickel; however, the effect of ingestion is excluded (Ref. G114).

It should, however, be noted that regulatory levels often take into account the uncertainty regarding unknown effects by employing safety factors.

It has been demonstrated that adverse health effects from major air pollution sources are related to the distance from that source. In the Rouyn-Noranda study (Ref. Q1), the health effects of cadmium and arsenic were determined to be worst in populations living closest to the smelter.

A compilation of data regarding human health effects of emissions from the eight non-ferrous smelters was based on information made available from a literature search, background material provided by EPS and data provided by provincial and industrial sources.

The main limitations encountered in the health effects review were the scarcity of ambient air monitoring data and epidemiological data. Of the eight smelters, only Noranda (Horne) and Noranda (Murdochville) had any information directly relating to human health effects.

The health effects review has been divided into sections on each of the eight smelters (Sections 5.1.2.1 to 5.1.2.8). These sections will summarize available human health related information, specifically pertaining to each smelter.

The subheadings for each smelter will be

- a) data sources
- b) local effects, and
- c) long range effects.

5.1.2.1 Inco (Sudbury)

Human health related information was not available.

5.1.2.2 Inco (Thompson)

Human health related information was not available.

5.1.2.3 Falconbridge (Sudbury)

Human health related information was not available.

5.1.2.4 Hudson's Bay Mining and Smelting (Flin Flon)

Human health related information was not available.

5.1.2.5 Noranda (Horne)

(a) Data Sources

The Quebec government undertook several health related studies in 1977 on the Rouyn-Noranda region. The "Bureau d'Etude sur les Substances Toxiques" (B.E.S.T.) prepared reports on the mortality level in the Rouyn-Noranda region (Ref. Q1), the distribution of toxic materials in the Rouyn-Noranda population (Ref. Q3) and an assessment of methods of evaluating and controlling the effects of these toxic materials in terms of the health of the population (Ref. Q4).

(b) Local Effects

The mortality study (Ref. Q1) compared the Rouyn-Noranda region with Drummondville, Val d'Or and the Province of Quebec.

An association was made between copper smelter emissions and excess lung cancer in men over 20 (including and excluding ex-workers) and excess respiratory diseases in men over 45 (including and excluding ex-workers). Not as clear was the significance of excess cardio-vascular illnesses and stomach cancers in the Rouyn-Noranda population. This study was not regarded as conclusive (Ref. Q17) with respect to the correlation between smelter emissions and health effects although it is supported by several other studies.

In the study regarding distribution of toxic materials in Rouyn-Noranda (Ref. Q3), blood and hair samples were taken from 527 persons (excluding Noranda workers) in seven zones. The first three zones were situated in the south end of Rouyn-Noranda, Zone No. 1 being the closest to the smelter. Zones 4 and 5 were two neighbouring communities, one 11 km east (McWatters), the other 8 km west (Evain), while zones 6 and 7 were Val d'Or (approx. 100 km east) and Ville Marie (approx. 100 km south), respectively. Samples were analyzed to determine concentrations of lead, cadmium, arsenic and mercury,

which are sources of emissions from the copper smelter that can be readily measured by biological parameters. The results confirmed that the copper smelter was a major source of contamination. The health hazard to the Rouyn-Noranda population posed by the major copper smelter emissions was addressed in the subsequent assessment (Ref. Q4).

The lead exposure level was not regarded as a real hazard to adults, but as the highest levels were found in children, B.E.S.T. recommended that follow-up lead tests include all children in the community, who are most in contact with soil dust, whose digestive absorption of lead is 4 times higher than adults and whose nervous system is more sensitive.

B.E.S.T. also recommended that lead emissions be reduced. Regarding SO_2 emissions, an epidemiological study on the respiratory functions of the Rouyn-Noranda population and an air monitoring program were recommended. A reduction in arsenic emissions was recommended to reduce the risk of lung cancer to Rouyn-Noranda residents. Reduction in cadmium, lead, zinc and SO_2 were all regarded as contributing factors to excess lung cancer in the mortality study (Ref. Q1) and reduction of emissions would therefore decrease the level of risk. B.E.S.T. determined that mercury and copper were not present in potentially hazardous levels to Rouyn-Noranda residents.

(c) Long Range Effects

Regarding the effects of the copper smelter on the surrounding populations and communities, B.E.S.T.'s study regarding distribution of toxic materials with respect to biological parameters was unable to address long range health effects in its scope of work in detail. The inherent difficulties with the test procedures precluded comprehensive and meaningful results.

The data indicated that biological exposure generally seemed to be proportional to distance from the source, and the levels were proportional to the relative concentrations of emissions. Baker and Landrigan (Ref. G61) determined that the levels of heavy metals in dust was inversely proportional to distance from the smelter. Although concern was expressed regarding cadmium and arsenic levels (mercury levels were regarded as low) found in the population group closest to the smelter, the major health concern expressed was lead exposure to children in that area.

With respect to long range effects, Baker et al (Ref. G62), Watson et al (Ref. G63) and Morton et al (Ref. G64) have found that there are higher concentrations of heavy metals in the homes of smelter workers, due to transport of dust from factory to homes.

5.1.2.6 Noranda (Murdochville)

(a) Data Sources

A study of absorption of several heavy metals on Murdochville children was undertaken by L. Chenard for a Master of Science Thesis (1983) at Laval University, Quebec (Ref. Q20).

The Murdochville population aged 2-12 years, considered to be at the highest risk, were tested for lead, arsenic and cadmium. Results obtained were used to evaluate the exposure to the general population. The City of Rimouski (200 km away) was used as a control.

(b) Local Effects

The study of the health impact of the mines and smelter complex on Murdochville children indicated that lead and arsenic were most likely being absorbed by the general population (not cadmium), and that both the environment and the homes of workers were important sources of exposure to residents.

Although the health of residents in general was not regarded to be immediately endangered by levels observed, chronic exposure to lead and arsenic especially to children and pregnant women was considered to possibly be the cause of yet unknown or subclinical physical and psychological illnesses.

In view of the above reasons and the possibility of increased risk from exposure to both lead and arsenic together, it was recommended that emission levels from the complex be reduced and measures taken to control the transport of dust from mines and smelter to homes.

(c) Long Range Effects

Children of workers that lived outside Murdochville were included in the study as a population group. No indication was given regarding the distance of these homes from the mine and smelter complex.

Results of this group indicated lower lead and arsenic exposures than the Murdochville population groups.

Transport of dust by workers from the mines and smelter complex to homes was considered as a significant source of exposure to Murdochville residents.

5.1.2.7 Brunswick Mining and Smelting (Belledune)

Specific human health related information was not available.

5.1.2.8 Cominco (Trail)

Specific human health related information was not available.

5.2 Other Environmental Effects

5.2.1 Introduction

The effects of heavy metals in the aquatic and terrestrial environments are the subject of a considerable volume of scientific literature. It is clear from this literature that the effects of a particular metal on specific plant or animal species can vary greatly depending upon the status of other environmental parameters at the time and place of exposure. In water or sediment, the availability or toxicity of a metal to aquatic biota can be greatly enhanced or reduced depending on pH, oxygen concentration, temperature, hardness or the concentrations of some metals and other chemical species which may act synergistically or antagonistically with the metal in question. The availability of metals in soils to plants and higher levels of the terrestrial food chain can be highly dependent on such factors as pH, soil texture, moisture content and the amount of humic matter in the soil.

In addition to these parameters, there is considerable variation in the sensitivity of different species and life stages to different metals. This is especially true for plants but may also occur in animals. For example, horses are much more sensitive to lead than other domestic ruminants. In the aquatic environment, the sensitivities of invertebrates are often much lower or higher than those of fish.

In view of the importance of other environmental parameters to metal toxicity and the differences in environmental effects which may occur depending on the composition of the affected biotic communities, it is expected that the environmental response to heavy metal deposition will vary geographically. Discussions of environmental effects in Section 5.2 are therefore limited mostly to those which have been documented with specific reference to each of the eight smelters under consideration.

Data from other smelters (eg. in the United States) have not been employed.

Two broad types of environmental effects have been described. Concentrations of heavy metals in environmental compartments (water, soil, vegetation, etc.) have been presented to indicate the area influenced by a smelter and the degree of contamination. This type of data was generally the most abundant. The second type deals with the toxic effects heavy metal contamination has had on populations or communities of plants and animals.

In extracting information from the available literature, care was taken to ensure that the effects described in this chapter resulted only from atmospheric deposition of heavy metals. Thus, effects in which sulphur dioxide emissions had a major role have been mostly excluded from the discussions. Water bodies receiving contaminated water from surface facilities have been similarly excluded from consideration.

Typical Levels of Heavy Metals in the Environment

Most of the data sets presented for each of the smelters and describing levels of environmental contamination include concentrations of heavy metals at distances beyond the effects of smelter emissions. These concentrations may be considered to approximate regional background levels. However, a somewhat broader perspective is provided by two tables in this section.

Table 5.2.1.1 shows typical concentrations of the eight heavy metals in water, sediment and fish and water quality objectives for the protection of aquatic life. Although all the metals are toxic to fish and other aquatic organisms, copper, mercury and cadmium are of particular concern.

Table 5.2.1.2 presents similar information with respect to the terrestrial environment, including: typical concentrations in soil and garden vegetables, soil concentrations causing toxic effects to plants and concentrations in plants which may be toxic to animals. The presence of cadmium, mercury and lead in plants is a major human health concern in contaminated areas. Cadmium in particular is readily taken up by plants from the soil.

TABLE 5.2.1-1

HEAVY METALS IN THE AQUATIC ENVIRONMENT¹

	As	Cd	Cu	Hg	Ni	Pb	Se	Zn
Normal concentrations in water (µg/L)	1-10	≤1-10	≤10	≤0.01- 0.1	≤100	1-100	≤0.1- 0.8	1-1000
Normal concentrations in sediment (µg/g)	0.5-14		0.5-100		1-85	≤300	0.2-2	50-200
Normal concentrations in fish (µg/g)	0.03-0.5	0.06- 0.14	0.5-1.5	≤0.5	0.1-0.2	≤0.5	0.06-2	10-20
Water quality objectives for the protection of aquatic life (µg/L)	50	0.2	2	0.1	25-250	5-10	10	50-300

¹ Derived from: Environment Canada, 1979-1981

TABLE 5.2.1.1-2

HEAVY METALS IN THE TERRESTRIAL ENVIRONMENT¹

	μg/g							
	As	Cd	Cu	Hg	Ni	Pb	Se	Zn
Normal concentrations in soil	0.5-20	0.06	2-100	≤0.005-1	5-500	2-200	0.1-2	10-300
Normal concentrations in garden vegetables (edible parts)	≤0.05- 0.5	≤0.01 -2.4	0.8-20	≤0.01- 0.02	0.03-7.4	0.05-19	≤0.01 -0.5	≤0.5-110
Soil concentrations above which toxic effects to plants may occur	5	2.5	25	no effects reported	25	50	30	50
Dietary concentrations above which toxic effects to domestic animals may occur	2.6	15	30	0.5	300	2	5	500

¹ Derived from: Environment Canada, 1979-1981; Ratsch, 1974 (E8); Shacklette et al, 1978; MOE, 1984

5.2.2 Inco (Sudbury)

5.2.2.1 Aquatic Environment

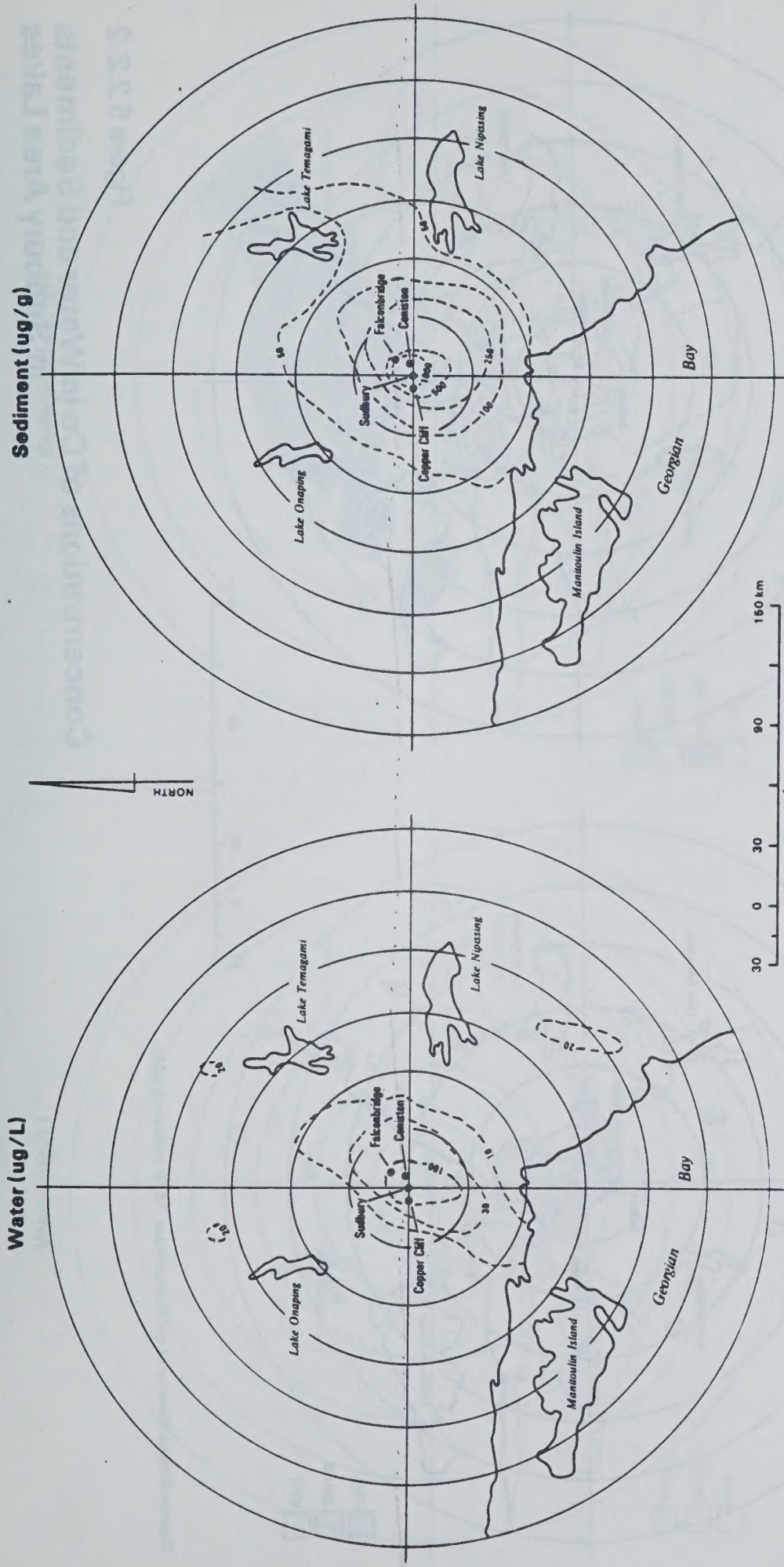
Studies on the effects of airborne heavy metal deposition on the aquatic environment have been undertaken in a regional context, without specific reference to any of the active or inactive smelters (Copper Cliff, Falconbridge, Coniston). This section has been prepared using regional data, but as Copper Cliff is the primary contributor to heavy metal pollution, the information is pertinent. Ontario Ministry of the Environment studies have selected a central reference point in Sudbury for use in describing effects over distance. The location of Copper Cliff is 6 km west of this reference point (see Figure 5.2.2-1).

Concentrations of Heavy Metals in Water

The concentrations of Zn, Cu, Ni, Pb, Cd and Fe in 214 Sudbury area lakes during 1974-76 are reported in MOE, 1978 (Ref. 048). The data for Ni, Cu and Zn are summarized in Figures 5.2.2-1, 5.2.2-2 and 5.2.2-3.

Nickel concentrations were generally greater than 100 µg/L within an average of 15 km from Sudbury and were significantly elevated (≥ 10 µg/L) for more than 60 km in the northeast and southwest directions. Background concentrations were typically ≤ 3 µg/L. Concentrations of Cu were greater than 20 µg/L within 15-50 km from Sudbury, depending on direction, compared to typical background concentrations of ≤ 5 µg/L. Zinc concentrations were greater than 30 µg/L in a north-south band within 15-20 km of Sudbury and also in an area 50-70 km to the southwest. As zinc is not abundant in the smelter emissions, the high zinc levels to the southwest may reflect geological variation or the low pH in the lakes of this area.

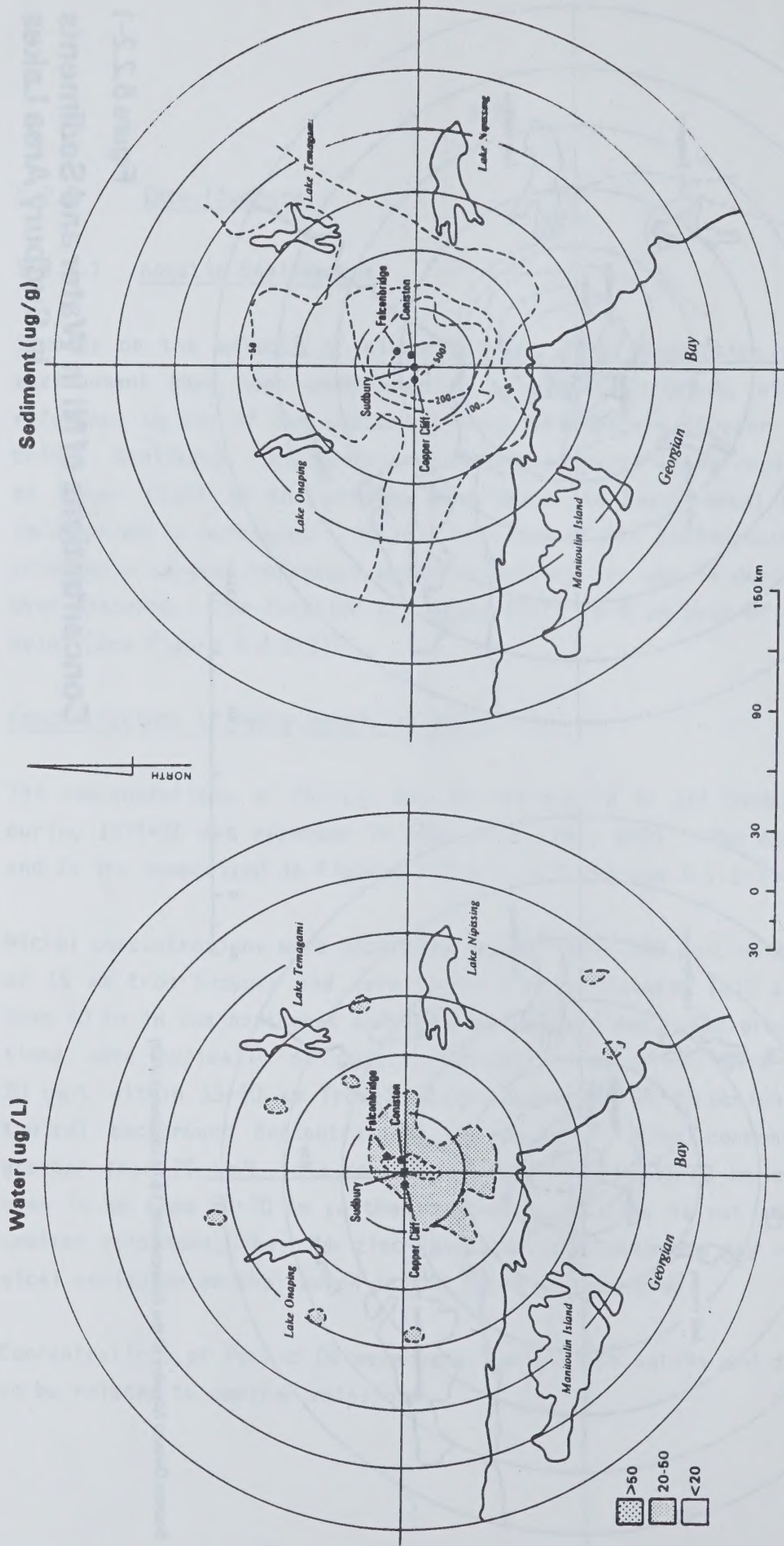
Concentrations of Pb and Cd were very low in lake waters and did not appear to be related to smelter emissions.



Source: Ontario Ministry of the Environment, 1978 (reference 048)

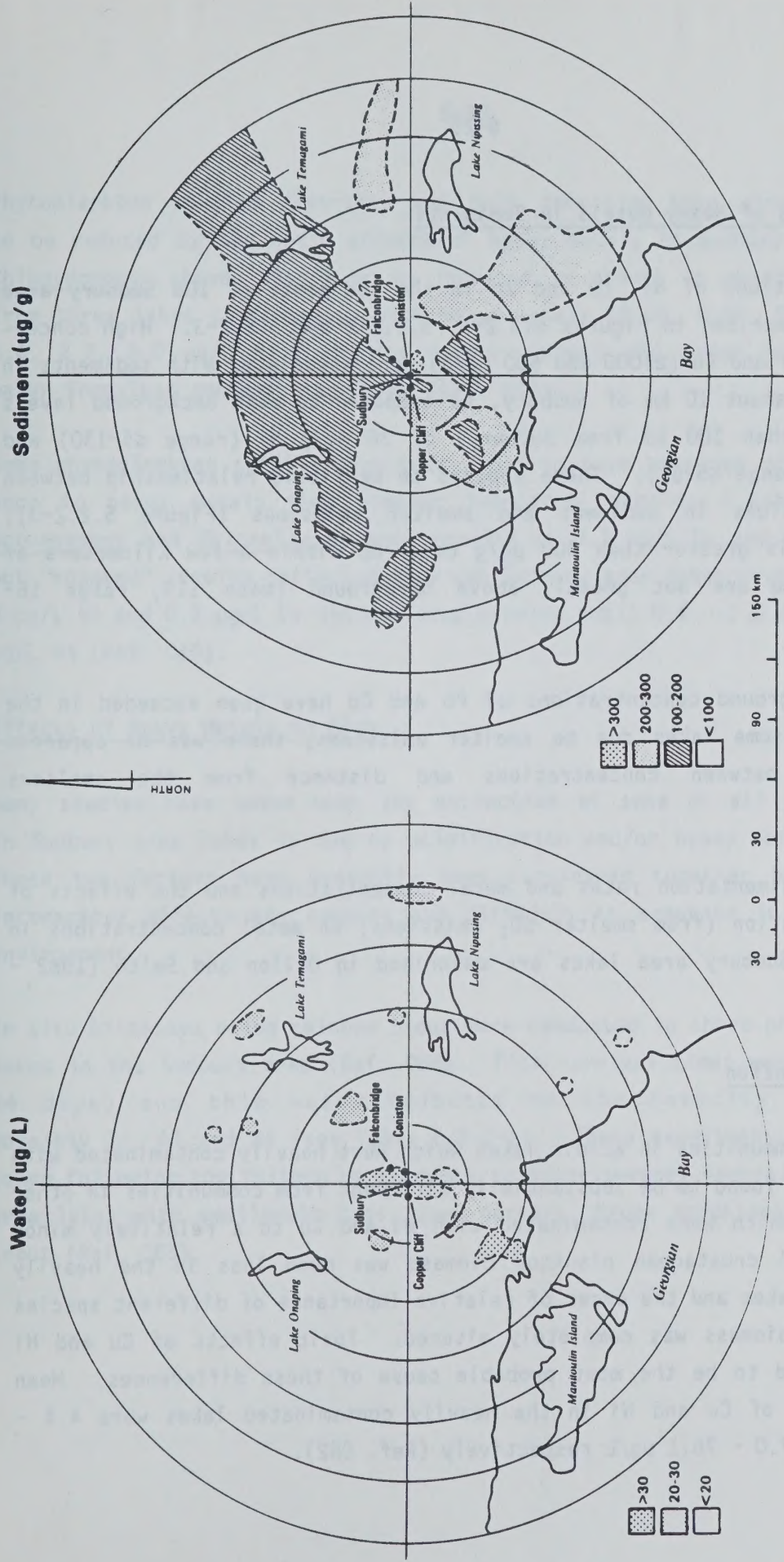
Figure 5.2.2-1

Concentrations of Ni in Water and Sediments in Sudbury Area Lakes



Source: Ontario Ministry of the Environment, 1978 (reference 048)

Figure 5.2.2-2
Concentrations of Cu in Water and Sediments
in Sudbury Area Lakes



Source: Ontario Ministry of the Environment, 1978 (reference 048)

Figure 5.2.2-3
Concentrations of Zn in Water and Sediments
in Sudbury Area Lakes

Concentrations of Heavy Metals in Sediments

The concentrations of Ni, Cu and Zn in the sediments of 106 Sudbury area lakes are summarized in Figures 5.2.2-1, 5.2.2-2 and 5.2.2-3. High concentrations of Ni and Cu (≥ 1000 and $500 \mu\text{g/g}$) were associated with sediments in lakes within about 10 km of Sudbury, as compared to mean background levels (lakes more than 100 km from Sudbury) of $36 \mu\text{g/g}$ Ni (range $\leq 5-130$) and $35 \mu\text{g/g}$ Cu (range $\leq 5-94$). There appears to be little relationship between Zn concentrations in sediment and smelter emissions (Figure 5.2.2-3); although levels greater than $300 \mu\text{g/g}$ occurred within a few kilometers of Sudbury, these are not greatly above background (mean 119, range 16-266 $\mu\text{g/g}$).

Although background concentrations of Pb and Cd have been exceeded in the sediments of some lakes due to smelter emissions, there was no apparent relationship between concentrations and distance from the smelters (Ref. 061).

Historical sedimentation rates and metal concentrations and the effects of lake acidification (from smelter SO_2 emissions) on metal concentrations in sediments of Sudbury area lakes are described in Dillon and Smith (1982 - Ref 061).

Effects on Plankton

Zooplankton communities in acidic lakes which were heavily contaminated with Ni and Cu were found to be substantially different from communities in other acidic lakes which were contaminated with Ni and Cu to a relatively minor extent. Total crustacean plankton biomass was much less in the heavily contaminated lakes and the order of relative importance of different species to the total biomass was completely altered. Toxic effects of Cu and Ni were considered to be the most probable cause of these differences. Mean concentrations of Cu and Ni in the heavily contaminated lakes were $4.4 - 17.8 \mu\text{g/L}$ and $7.0 - 76.1 \mu\text{g/L}$ respectively (Ref. 062).

Phytoplankton species diversity and cell densities have also been shown to be reduced by the toxic effects of heavy metals in Sudbury area lakes. Chlamydomonas showed little or no increase in growth in pH-adjusted water from three lakes contaminated with heavy metals (0.06, 0.52, 0.49 $\mu\text{g/L}$ Cu; 6.4, 2.7, 3.0 $\mu\text{g/L}$ Ni), whereas greater growth did occur in pH-adjusted water from less contaminated lakes (Ref. 033).

Some phytoplankton species have been found to have attained greater tolerance to heavy metals than similar laboratory strains. Lab strains of Scenedesmus and Chlorella stopped growing at 0.1 $\mu\text{g/L}$ Cu and 0.5 $\mu\text{g/L}$ Ni, but "adapted" strains collected from two Sudbury area lakes containing up to 3 $\mu\text{g/L}$ Ni and 0.7 $\mu\text{g/L}$ Cu did not stop growing until 0.4 - 1.0 $\mu\text{g/L}$ Cu and 3 $\mu\text{g/L}$ Ni (Ref. 019).

Effects of Heavy Metals on Fish

Many studies have shown that the extinction of some or all fish species in Sudbury area lakes is due to acidification and/or heavy metal toxicity. These two factors have generally been considered together because their interactive effects are complex and difficult to separate in the natural environment.

In situ bioassays using rainbow trout were conducted in three pH-neutralized lakes in the Sudbury area (Ref. 063). Fish survival times were low (2.3 - 34 days) and this was attributed to the toxicity of Cu and possibly Zn, Al and Ni (see Table 5.2.2-1). These experiments were undertaken following the failure of attempts to stock several neutralized Sudbury area lakes with smallmouth bass, Iowa darters, brook stickleback and brook trout (Ref. 063).

TABLE 5.2.2-1

GEOMETRIC MEAN SURVIVAL TIME (GMST) OF RAINBOW TROUT
AND METAL CONCENTRATIONS IN SUDBURY AREA LAKES¹

Lake	n ²	pH	$\mu\text{g/L}$				GMST ³ (days)
			Al	Cu	Ni	Zn	
Middle	5	6.4	53	53	406	27	3.6(2.1-5.7)
Lohi	3	5.3	97	43	227	31	2.3(1.3-3.5)
Panache	1	6.5	-	6	28	6	34.0

¹ From Yan and Dillon, 1982 (Ref. 063)

² Number of experiments.

³ Range in brackets.

5.2.2.2 Terrestrial Environment

Concentrations of Heavy Metals in Soil

Soil studies in the Sudbury area have mostly been concerned with the highly contaminated and eroded soils near the Coniston smelter, which was closed in 1972 (e.g. Ref. 024, 020, 032). Table 5.2.2-2 shows the concentrations of ten metals in soils from sites 1-50 km south and east of the Coniston smelter. The main soil contaminants, Ni and Cu, are present at very high concentrations within about 20 km of the smelter and do not approach background levels until more than 30 km away. Normal Canadian Shield values for Ni and Cu, as quoted in Hazlett et al (1984) (Ref. 032) are 12 and 11 $\mu\text{g/g}$ respectively. Co, Ag, Pb and Fe concentrations are also elevated near the smelter, but to a comparatively minor degree. Concentrations of other metals (Zn, Mn, V) appear to have been unaffected by smelter emissions.

No studies were identified which have analyzed soils close to the Copper Cliff smelter for heavy metal content. However, the influence of this smelter at greater distances can be seen in Table 5.2.2-3. Sites in this table are all closer to Copper Cliff than to either of Coniston or Falconbridge. The concentrations of Ni, Cu and As are all elevated close to the smelter and show a gradual decline with increasing distance. Concentrations of Ni and Cu are still about four times background at 25 km to the south-west. Levels of Se, Zn, Pb and Co do not appear to be influenced by smelter emissions at the distance shown (≥ 7 km). A comparison of Tables 5.2.2-2 and 5.2.2-3 indicates that soils south-east of Coniston are considerably more contaminated by Ni and Cu than to the south-west of Copper Cliff within about 20 km of the smelters.

Concentrations of heavy metals in soils at different distances from the Sudbury smelters are shown graphically in Figures 5.2.10-1 to 5.2.10-7.

In the vicinity of the Coniston smelter, it was found that metal contamination was generally greatest at sites where deposition of eroded soil

TABLE 5.2.2-2

CONCENTRATIONS OF HEABY METALS IN SOILS SOUTH
AND EAST OF THE CONISTON SMELTER IN 1969¹

Distance from smelter (km)	$\mu\text{g/g}$									
	Cu	Ni	Co	Zn	Ag	Pb	Mn	Fe	Al	V
1.1	2892	5104	199.5	96.3	7.9	82.5	255.4	77,500	11,010	103.3
1.5	2162	1856	81.4	76.5	9.0	38.4	196.8	68,500	37,190	63.4
1.6	2416	1851	80.4	65.2	3.5	52.8	202.0	28,680	2,825	62.8
2.1	1985	3928	193.1	71.5	4.6	91.7	232.0	108,400	4,544	104.8
2.2	2418	2337	92.5	82.5	7.8	58.2	173.8	61,675	35,870	115.0
2.9	1657	1203	41.0	50.1	3.3	48.2	143.3	20,625	12,495	25.4
7.4	1371	1771	46.5	87.6	2.9	45.7	299.0	39,750	35,700	164.7
10.4	287	282	54.1	72.0	2.3	27.8	363.7	35,440	15,738	137.9
13.5	233	271	42.0	100.0	4.3	22.6	602.7	56,000	39,440	151.2
19.3	184	306	24.4	61.0	nd*	28.2	264.0	14,525	9,377	55.3
24.1	45	101	18.0	46.0	5.5	18.8	207.1	17,000	16,330	33.5
32.1	46	35	16.5	55.4	1.9	26.3	195.0	18,500	11,305	96.0
38.6	2	39	28.9	61.6	nd*	28.2	192.0	38,275	19,312	169.0
49.8	26	35	22.4	83.5	1.0	20.1	168.2	11,565	2,197	23.1

1 from Hutchinson and Whitby, 1974 (Ref. 020)

* nd = not detectable.

TABLE 5.2.2-3

MEAN OF MEAN ANNUAL (1970-76) CONCENTRATIONS OF HEAVY METALS
IN SOILS AT VARIOUS DISTANCES FROM COPPER CLIFF AND FALCONBRIDGE^{1,2}

Distance (km) and direction from smelter		µg/g						
		Ni	Cu	As	Se	Zn	Pb	Co
Copper Cliff								
7	S ³	110	85	11.2	-	52	23	7
10	N	93	78	8.0	0.42	19	21	5
14	NW	31	19	2.5	0.23	39	17	7
16	W ³	53	30	7.2	-	45	20	17
18	SW	57	58	6.2	0.32	74	40	10
25	SW	40	39	3.4	0.37	73	32	8
155	W	10	11	2.2	0.49	38	17	8
Falconbridge								
5	NNE	124	144	21	0.64	58	32	10
13	NE	62	63	8.3	0.80	38	22	11
26	NNE ³	37	21	4.0	-	15	15	7
28	NE	51	43	7.4	0.23	67	35	12
46	NE	36	33	4.4	0.40	39	18	11
169	E	14	6	1.8	0.20	25	8	4

¹ derived from Ontario Ministry of the Environment, 1978 (Ref. 046).

² Se only in 1970 and/or 1972; Zn and Co only 1970-73; Pb only 1973, 1975, 1976

³ No sampling 1970-72

TABLE 5.2.2-4

MEAN OF MEAN ANNUAL (1970-76) CONCENTRATIONS OF
HEAVY METALS IN FOLIAGE OF WHITE BIRCH AT VARIOUS DISTANCES FROM
COPPER CLIFF AND FALCONBRIDGE^{1,2}

Distance (km) and direction from smelter		$\mu\text{g/g}$ (dry wt.)						
		Ni	Cu	As	Se	Zn	Pb	Co
Copper Cliff								
7	S ³	65	23	1.1	0.42	193	12	2
10	N	50	19	1.1	0.38	152	9	3
14	NW	17	13	0.7	0.30	208	9	3
16	W ³	16	8	0.4	0.27	216	7	4
18	SW	18	12	0.6	0.33	210	10	4
25	SW	10	10	0.7	0.19	278	9	4
155	W	6	7	0.5	0.20	380	6	5
Falconbridge								
5	NNE	84	35	3.9	0.48	141	10	4
13	NE	35	18	1.5	0.60	166	7	4
26	NNE ³	20	9	0.7	0.18	169	8	3
28	NE	15	11	0.8	0.55	189	7	4
46	NE	14	12	0.7	0.46	199	8	4
169	E	6	7	0.5	0.44	270	5	4

¹ derived from Ontario Ministry of the Environment, 1978 (Ref. 046).

² Se only in 1970, 1972, 1973; Zn and Co only 1970-73; Pb only 1973, 1975, 1976.

³ No sampling 1970-72

materials is greatest (valleys, depressions) and in poorly drained soils (Ref. 024). Extensive soil erosion within about 2.5 km of Coniston has removed contaminated soils on summits and slopes to lower areas, where high metal levels may exist at depth, rather than being largely confined to the surface (Ref. 032).

High concentrations of Ni and Cu occurred in wetland soils near Copper Cliff and decreased with distance from the smelter (Ref. 025). Concentrations were generally similar to those in forest soils.

Concentrations of Heavy Metals in Vegetation

Metal concentrations in white birch, trembling aspen, jack pine, bracken fern and grass were examined by the Ontario Ministry of the Environment (1978 - Ref. 046) between 1970 and 1976. The data for white birch from sites at different distances from Copper Cliff are summarized in Table 5.2.2-4. Fairly high levels of Ni (≥ 50 $\mu\text{g/g}$) and Cu (≥ 19 $\mu\text{g/g}$), compared to background (6-7 $\mu\text{g/g}$), occurred within 10 km of the smelter and As levels were also somewhat elevated near the smelter (1.1 $\mu\text{g/g}$). The concentrations which MOE (Ref. 046) considers "excessive" are: Ni and Cu - 30 $\mu\text{g/g}$ and As - 8 $\mu\text{g/g}$. The concentrations of Se, Zn, Pb and Co showed little relationship with distance from the smelter. Maximum mean annual concentrations of metals in white birch at any of the sites described in Ref. 046, including "Garson" and "Sudbury", were as follows: Ni - 133 $\mu\text{g/g}$; Cu - 61 $\mu\text{g/g}$; As - 4.4 $\mu\text{g/g}$; Se - 1.06 $\mu\text{g/g}$; Zn - 607 $\mu\text{g/g}$; Pb - 14 $\mu\text{g/g}$; Co - 10 $\mu\text{g/g}$. White birch and trembling aspen generally had somewhat higher concentrations of metals than the other plant species.

Concentrations of Ni, Cu and Fe were measured in lichens along a transect running 96 km north-north-west from Copper Cliff (Ref. 034). Lowest and highest concentrations at 8 km and 96 km respectively were: Ni - 8-310 $\mu\text{g/g}$; Cu - 15-250 $\mu\text{g/g}$. Concentrations were very close to background at about 60 km from the smelter.

Concentrations of Heavy Metals in Animals

Concentrations of Cu, Ni and Fe in kidney, liver and muscle tissue of ruffed grouse from a site near Sudbury (5 km from Falconbridge, 20 km from Copper Cliff) and from a background site are shown in Table 5.2.2-5. Diets of grouse from the two sites were essentially the same (aspen leaves; leaves and fruits of a variety of shrub species; mushrooms).

Concentrations of Ni in kidney and liver averaged nearly three times higher at the Sudbury site but there was little difference in the levels of Cu and Fe between sites. Concentrations of Ni and Cu were much higher in crop items and dung at the Sudbury site. The concentrations of Ni in food items at the Sudbury site (up to 136 $\mu\text{g/g}$) were less than the minimum concentrations at which measurable toxic effects in birds have been detected in laboratory studies (800 $\mu\text{g/g}$) (in Ref. 031).

Effects of Heavy Metals on Soils

Freedman and Hutchinson (1980) (Ref. 023) examined the effects of heavy metals at sites from 3.5-34 km from Copper Cliff on forest leaf litter decomposition. Mean litter standing crop was about 2.5 times higher at 5 km from the smelter, compared to 35 km away, despite greater leaf fall at more distant sites. Reduced litter decomposition was found to be related to soil Ni and Cu concentrations. Reduced soil enzyme activity, CO_2 flux, soil fauna populations and soil fungal populations all occurred at more contaminated sites. It appeared that the effects of Cu were greater than those of Ni.

Effects of Heavy Metals on Vegetation

The loss of vegetation in the Sudbury area, such as around the Coniston smelter, has been attributed primarily to sulphur dioxide emissions. The

TABLE 5.2.2-5

MEAN CONCENTRATIONS ($\pm$ SE) OF Cu, Ni AND Fe
IN RUFFED GROUSE TISSUES FROM THE SUDBURY AREA

Tissue and Element	$\mu\text{g/g}$ (dry wt.)			
	Blewett ²		Falconbridge ³	
	May	September	May	September
Kidney				
Cu	19.8 $\pm$ 0.9	11.7 $\pm$ 1.3	24.6 $\pm$ 1.7	14.8 $\pm$ 1.5
Ni	1.7 $\pm$ 1.0	ND ⁴	2.8 $\pm$ 0.6	2.1 $\pm$ 0.7
Fe	386 $\pm$ 29	255 $\pm$ 9	254 $\pm$ 30	254 $\pm$ 14
Liver				
Cu	16.3 $\pm$ 0.8	12.6 $\pm$ 0.5	13.5 $\pm$ 0.7	14.5 $\pm$ 0.9
Ni	0.9 $\pm$ 0.3	0.7 $\pm$ 0.3	3.5 $\pm$ 0.3	3.5 $\pm$ 0.6
Fe	2452 $\pm$ 333	1899 $\pm$ 133	1519 $\pm$ 495	3905 $\pm$ 523
Muscle				
Cu	2.3 $\pm$ 0.2	1.5 $\pm$ 0.1	1.9 $\pm$ 0.1	1.5 $\pm$ 0.1
Ni	ND	0.2 $\pm$ 0.1	1.4 $\pm$ 0.8	0.2 $\pm$ 0.1
Fe	15 $\pm$ 1	11 $\pm$ 1	20 $\pm$ 4	12 $\pm$ 1

¹ from Rose and Parker, 1983 (Ref. 031); n = 9-11.

² 100 km north of Sudbury (47° 15' N, 81° 30' E)

³ 5 km from Falconbridge smelter, 20 km from Copper Cliff smelter
(46° 32' N, 80° 45' E)

⁴ Below detection limit for all samples.

role played by heavy metals in the disappearance of this vegetation has not been clearly described, although it is known that the concentration of heavy metals in soils close to the smelters are toxic to plants. In Europe and the United States, revegetation of denuded areas has often not occurred naturally within 70 years of the closure of a smelter (Ref. 021), generally as a result of high levels of various heavy metals in soils.

Whitby and Hutchinson (1974 - Ref. 021) measured root elongation in germinating seeds of lettuce, tomato, radish and cabbage exposed to soil-water extracts from sites located 0.8 to 49.8 km from the Coniston smelter. Within 3.8 km of the smelter and irrespective of soil sample depth (1, 5 and 10 cm), there was almost total inhibition of root elongation and roots were deformed. The minimum total concentrations in soil of Ni and Cu within 3.8 km were 649 $\mu\text{g/g}$ and 944 $\mu\text{g/g}$ respectively (Ref. 020). Soils were found to be toxic up to 10.4 km from the smelter. In soil-water extracts, Ni, Cu and Al were the main contaminants and concentrations decreased with distance. The presence of a distance relationship for Al was thought to reflect the lower pH of soils near the smelter. Ni, Cu, Co and Al were all found to be markedly inhibitory to seedling growth at soil-water extract concentrations above 5 $\mu\text{g/L}$. Almost total inhibition of root growth occurred at the following concentrations, with the approximate maximum distance from the smelter at which these occurred in brackets: Ni - 10 $\mu\text{g/L}$ (6 km); Cu - 15 $\mu\text{g/L}$ (1.9 km); Co - 15 $\mu\text{g/L}$ (did not occur); Al - 4 $\mu\text{g/L}$ (10.4 km).

Lime amendments to soils from various distances from Coniston had dramatic effects on growth and survival of seedlings and resulted in significant reductions in metal uptake by plants. However, no seedlings survived on soils within 7.4 km of Coniston (Ref. 033).

5.2.3 Inco - Thompson

5.2.3.1 Aquatic Environment

No useful data have been found concerning the effects of heavy metal emissions from the smelter at Thompson on the aquatic environment. Although concentrations of heavy metals were measured in fish, benthic invertebrates, zooplankton and sediments from three lakes east and north-east of the smelter, it was subsequently determined that all lakes represented background conditions (Ref. M14). The nearest lake was 26.5 km from the smelter.

5.2.3.2 Terrestrial Environment

Concentrations of heavy metals in soil

The most extensive soil data are contained in Phillips and Slaney (1981 - Ref. M14) although good data for Cu, Ni and Zn are also found in Wotton and Hogan (1981 - Ref. M19) and for Cu, Ni and As in Hocking and Blauel (1977 - Ref. M7).

Concentrations of Ni, Cu, Co, As, Cd, Pb and Zn in the surface organic layer of the soil (LFH) at various distances south-east of the smelter are shown in Table 5.2.3-1 and in Figures 5.2.10-1 to 5.2.10-7. These data, from Phillips and Slaney (1981), are generally supported by similar results in the other two studies.

Concentrations of Ni and Cu were about 100 times and 50 times background respectively at a distance of 1.5 km from the smelter and did not approach background levels until about 40 km away. Levels of Co and As were only markedly above background at the closest site (1.5 km from smelter) and were essentially at background by 13.5 km. The limited data for Cd, Pb and Zn suggest that smelter emissions are having little influence on the concentrations of these metals in soil.

TABLE 5.2.3-1

MEAN CONCENTRATIONS OF HEAVY METALS
IN THE LFH LAYER AT JACK PINE SITES LOCATED
SOUTH-EAST OF THE INCO SMELTER AT THOMPSON¹

Distance from Smelter (km)	$\mu\text{g/g}$ (dry wt.)						
	Ni	Cu	Co	As	Cd	Pb	Zn
1.5	2688	544	66	41	0.5	19	63
4.5	707	70	17	6	0.6	24	58
7.3	701	67	15	5	— ³	—	—
13.5	421	55	8	3	—	—	—
21.0	162	22	5	4	—	—	—
31.0	86	27	9	4	—	—	—
42.0	76	15	7	3	—	—	—
77.0	25	9	3	1	—	—	—
60.0 (N-E) ²	31	11	5	2	0.3	11	57

¹ From Phillips and Slaney, 1981 (Ref. M14)

² Background site location north-east of smelter

³ No data

Data in Phillips and Slaney (1981) indicate that heavy metal depositions are being retained in the LFH layer. The only exceptions were: 1) an increase (about 20%) in Ni concentration in the underlying A horizon 1.5 km from the smelter; 2) elevated levels of Ni, Cu and Co in the 5-15 cm peat layer of a fen 4.5 km from the smelter.

Concentrations of heavy metals in vegetation

There is considerable information on heavy metal concentrations in vegetation from the Thompson area. The most extensive data set, in terms of number of plant species, number of sampling sites and number of metals analysed, is contained in Phillips and Slaney (1981 - Ref. M14). However, good data on Ni and Cu in jack pine, alder and Labrador tea are presented in Wotton and Hogan (1981 - Ref. M19); Hocking and Blauel (1977 - Ref. M7) analysed Ni and Cu in jack pine, lichens and mosses and As in jack pine.

Concentrations of Ni, Cu, Co, As, Cd, Pb and Zn in jack pine needles are shown in Table 5.2.3-2. The relationships between metal concentrations and distance from the smelter is similar to that found in soils (Table 5.2.3-1) and the results are similar, allowing for species differences, to other sets of data (Ref. M14, M19). The concentrations of Ni, Cu and Co were all elevated 10-15 times above background close to the smelter (1.5 km) but were considerably lower at 4.5 km. The distances from the smelter at which Ni, Cu and Co concentrations were similar to background are about 25 Km, 15 Km and 6 Km respectively. As and Cd were slightly elevated at 1.5 km but were similar to background at greater distances. Concentrations of Pb and Zn appear to be unrelated to smelter emissions.

Uptake of heavy metals varies considerably between plant species. Table 5.2.3-3 shows the concentrations of the principal contaminants (Ni, Cu, Co) in a variety of species at a site close to the smelter and at a background site. In general, bryophytes (mosses etc) and lichens tend to

TABLE 5.2.3-2

MEAN CONCENTRATIONS OF HEAVY METALS IN
JACK PINE FOLIAGE (1977) AT SITES LOCATED
SOUTH-EAST OF THE INCO SMELTER AT THOMPSON¹

Distance from Smelter (km)	$\mu\text{g/g}$ (dry wt.)						
	Ni	Cu	Co	As	Cd	Pb	Zn
1.5	73	38	18	4.9	1.1	3.4	31
4.5	24	11	4.0	0.4	0.8	2.3	46
7.3	1.22	6.0	1.3	2.3	0.2	5.2	31
13.5	17	4.1	1.2	-	≤ 0.1	0.4	49
21.0	11	2.0	-	0.4	0.4	2.5	60
31.0	4.7	2.9	0.1	0.2	≤ 0.1	2.1	51
60.0 (N-E) ²	4.5	3.2	1.2	0.5	2.8	2.5	39

¹ From Phillips and Slaney, 1981 (Ref. M14)

² Background site location north-east of smelter

TABLE 5.2.3-3

CONCENTRATIONS OF Ni, Cu AND Co IN FOLIAGE
FROM DAM B (4.5 km FROM SMELTER) AND
ORR LAKE (60 km FROM SMELTER)¹

Plant Species	$\mu\text{g/g}$ (dry wt.)					
	Ni		Cu		Co	
	Dam B	Orr Lake	Dam B	Orr Lake	Dam B	Orr Lake
<u>Trees/Shrubs</u>						
Salix spp	21.0	2.5	3.5	2.0	0.5	1.0
Betula glandulosa	55.0	6.0	7.0	5.0	6.0	0.5
Ledum groenlandicum	29.0	1.5	5.0	3.0	0.5	0.5
<u>Herbaceous ssp</u>						
Cornus canadensis	51.0	7.0	10.0	5.0	0.5	2.0
Linnaea boeorealis	230.0	5.0	88.0	4.5	18.0	5.0
Carex sp	8.1	3.4	3.1	1.7	2.6	0.9
<u>Bryophytes</u>						
Tomenthypnum nitens	188.0	14.0	63.0	5.4	18.0	2.7
Sphagnum spp	188.0	18.0	69.0	5.3	19.0	1.4
<u>Lichen</u>						
Evernia mesomorpha	321.0	20.5	110.0	5.8	15.0	1.7

¹ From Phillips and Slaney (1981) (Ref. m14)

accumulate the greatest amounts of metals. Maximum concentrations of Ni, Cu and Co were 321, 110 and 19 µg/g respectively. Note that background concentrations are also generally much higher in bryophytes and lichens than in jack pine and other species.

Concentrations of heavy metals in wildlife

Concentrations of Ni, Cu, Co, As, Cd, Pb and Zn in small mammals at a site near the smelter and at a background site are shown in Table 5.2.3-4. The species sampled were red-back voles (Clethrionomys gapperi), red squirrels (Tamiasciurus hudsonicus), mice (Peromyscus spp.), snowshoe hares (Lepus americanus) and shrews (Sorex spp.).

Overall, it appears that smelter emissions were having little effect on heavy metal accumulation in mammals, with the possible exceptions of Ni and Co. In six of seven pairs of Ni analyses, the mean concentration was greater at the site closer to the smelter, although in only two cases was the difference statistically significant. Mean Co concentrations were higher near the smelter in four of seven pairs of analyses, with the differences being statistically significant in three of these. No smelter effect is suggested by the Cu, As, Cd, Pb or Zn data.

Effects of heavy metals on vegetation

Extensive studies during 1977-79 did not reveal any significant relationship between distance from the smelter and tree or shrub mortality, tree or shrub density or tree growth (Ref. M14, M19).

Also, Phillips and Slaney (1981 - Ref. M14) indicated that excellent re-growth of black spruce was occurring along cut lines and winter roads near the smelter.

TABLE 5.2.3-4

MEAN CONCENTRATIONS OF HEAVY METALS IN MAMMALS
FROM DAM B (4 km FROM SMELTER) AND
ORR LAKE (60 km FROM SMELTER)¹

Sample	Location ²	n ³	$\mu\text{g/g}$ (dry wt.)						
			Ni	Cu	Co	As	Cd	Pb	Zn
Voles (liver)	D	2	4.0	15*	1.2*	0.15	0.40	1.07	84
	O	9	3.8	19	0.6	0.27	0.63	0.34	90
Squirrels (liver)	D	3	2.3	21	1.3	0.13*	— ⁴	0.15	107
	O	7	0.8	22	1.5	0.24	—	0.15	95
Mice (liver)	D	5	5.0	19	1.0	0.19	0.36	0.75	95
	O	1	1.2	21	0.5	0.20	0.40	0.80	95
Hares (liver)	D	8	0.5*	15	0.8	0.08*	—	0.31	119
	O	12	0.4	17	0.8	0.10	—	0.23	124
Hares (thigh muscle)	D	13	2.4	6	0.4*	0.09	0.15	0.16	61
	O	26	2.0	7	0.3	0.06	0.09	0.10	59
Hares (calf muscle)	D	6	3.5	8	0.2*	0.05	0.05	0.46	102
	O	20	3.6	7	0.5	0.05	0.06	0.45	94
Shrews (whole)	D	21	5.2*	15	1.1*	0.03	0.25*	0.07	111
	O	22	3.3	16	0.3	0.03	0.34	0.08	112

¹ From Phillips and Slaney, 1981 (Ref. M14)

² D = Dam B; O = Orr Lake

³ n was slightly less than indicated for some analyses (n = sample size)

⁴ No data

* difference between Dam B and Orr Lake results statistically significant (P $\leq$.05)

However, there has been a significant decline in total ground cover near the smelter. Bryophyte and lichen cover was almost totally eliminated at most study sites within 8 km of the smelter to the south-east, south and south-west. South-east of the smelter, where metal deposition is heaviest, a progressive decline in bryophyte and lichen cover and species diversity towards the smelter was observed from about 20 km away, (Table 5.2.3-5).

Wotton and Hogan (1981 - Ref. M19) examined the growth characteristics of jack pine seedlings grown in LFH soils collected from five sites at distances of 2.3 - 66 km from the smelter. After 14 weeks, eight growth parameters (e.g. seedling length, root mass, % needle dieback) were measured (Table 5.2.3-6). The results indicated that the LFH soils at the closest site (730 $\mu\text{g/g}$ Cu, 2290 $\mu\text{g/g}$ Ni) were toxic to jack pine seedlings in terms of reduced growth performance, although there was no significant effect on seedling establishment or mortality. Seedlings grown on soils from this site produced abnormal bud-like outgrowths on secondary roots, a characteristic often associated with excess copper. The results at the closest site suggest that the metal levels occurring there approximate the maximum tolerable levels with respect to seedling establishment.

Effects of heavy metals on wildlife

The only studies to examine the effects of heavy metal emissions on wildlife were carried out as part of the Inco Thompson Environmental Program (Ref. M14). Physical measurements of shrews, voles, mice and snowshoe hares (hind foot length, total weight etc) from sites 4 km and 60 Km from the smelter did not show that smelter emissions or metal concentrations in vegetation were having any effect on growth of small mammals. Voles and shrews appeared to be less abundant and mice more abundant at the closest site. However these differences may reflect variation in habitat.

TABLE 5.2.3-5

PERCENT COVER AND NUMBER OF SPECIES OF BRYOPHYTES AND
LICHENS AT VARIOUS DISTANCES FROM THE SMELTER AT THOMPSON¹

Direction from Smelter	Distance from Smelter (km) ²							
	≤2.0	2.1-5.0	5.1-10	11-15	16-20	21-30	31-40	≥40
Jack Pine Subsites								
SE and E								
% Cover	0	0.2	17.8	33.3	— ⁴	48.7	34.9	16.7
n ³	0	2	4	7	—	6.5	6	3
S and SW								
% Cover	0	1.7	12.9	—	51.3	68.1	33.1	52.4
n	0	5	7	—	5	8	6	6
NW, N and NE								
% Cover	—	—	37.4	28.1	42.5	57.2	—	35.8
n	—	—	7.5	6	13	8.5	—	8
Black Spruce Subsites								
SE and E								
% Cover	0	1.0	15.1	38.7	75.4	74.0	90.5	94.9
n	0	4	4	3	6	7	6	6
S and SW								
% Cover	1.5	18.3	30.4	—	43.9	52.3	67.9	60.2
n	1	3	5	—	9	8	7.5	6.7
NW, N and NE								
% Cover	—	—	42.0	58.6	95.8	88.9	—	95.0
n	—	—	7	6.5	10	9.7	—	9.5

¹ Derived from Phillips and Slaney, 1981 (Ref M14)² Where more than one subsite occurred within a distance interval, data have been averaged³ Number of species of bryophytes and lichens present⁴ No data

TABLE 5.2.3-6

CHARACTERISTICS OF JACK PINE SEEDLINGS GROWN ON LFH
MATERIAL FROM 5 SITES IN THE THOMPSON AREA¹

Seedling Parameter	Distance from Smelter (km)				
	2.3	4.0	9.0	12.2	66.0
Seedling length (cm)	5.3	19.4	18.4	23.3	20.1
Shoot Length (cm)	3.9	5.0	5.0	5.6	5.1
Root Length (cm)	1.3	14.4	13.5	17.7	15.1
Oven dry root mass (g/100 seedlings)	0.3	1.9	2.0	3.5	2.7
Oven dry shoot mass (g/100 seedlings)	1.0	3.2	2.9	5.2	4.3
Oven dry seedling mass (g/100 seedlings)	1.3	5.1	4.9	8.7	7.0
% Chlorosis incidence	90	7	0	0	0
% needle dieback incidence	97	83	28	43	24
Ni in LFH ($\mu\text{g/g}$ dry wt.)	2290	1090	390	260	50
Cu in LFH	730	320	100	70	10

¹ From Wotton and Hogan, 1981 (Ref. M19)

5.2.4 Falconbridge

5.2.4.1 Aquatic Environment

From a comparison of particulate emissions at Copper Cliff and Falconbridge (Tables 3.1.1-4 and 3.1.2-3), it can be seen that annual atmospheric emissions of heavy metals from Falconbridge are small compared to those from Copper Cliff. The quantities of metals emitted from Falconbridge, expressed as a percentage of those from Copper Cliff, are as follows: Fe - 5.8%; Ni - 2.0%; Cu - 1.7%; Pb - 7.0%; As - 5.4%; Zn - 4.8%; Cd - 12.2%.

The determination of environmental effects of Falconbridge heavy metal emissions cannot readily be separated from those of Copper Cliff emissions due to much greater emissions from Copper Cliff and the proximity of the two smelters (16 km apart). Elevated levels of Ni and Cu have been found in aquatic systems 60 km from Sudbury (see Figure 5.2.2-1). Past atmospheric depositions from Coniston emissions also contribute to the metal loadings of Sudbury area lakes.

No studies on the effects of heavy metals on the aquatic environment specifically referenced to the Falconbridge smelter have been seen. However, as the metals emitted by Falconbridge are the same as those emitted by Inco at Copper Cliff, the regional discussion presented in Section 5.2.2-1 provides a "generic" summary of effects.

5.2.4.2 Terrestrial Environment

No studies specific to the Falconbridge smelter have been reviewed. However Reference 046 (Ontario MOE, 1978) provides soil and vegetation data for several sites to the north-east of this smelter. These data are described in this section.

The discussion of effects of heavy metals on the terrestrial environment with respect to Copper Cliff (Section 5.2.2-2) is also pertinent to Falconbridge since the same metals are emitted by both smelters.

Concentrations of Heavy Metals in Soil

Concentrations of Ni, Cu, As, Se, Zn, Pb and Co in soils from five sites located in a generally north-east direction from the Falconbridge smelter plus a background site to the east are shown in Table 5.2.2-3 and Figures 5.2.10-1 to 5.2.10-7. Concentrations of Ni, Cu, As and Se are distinctly elevated within 13 km of the smelter. These levels tend to be higher than at similar distances from Copper Cliff (Table 5.2.2-3), probably as a result of contributions from both smelters. For example, the site which is closest to Falconbridge (5 km) is 20 km from Copper Cliff. At this site, Ni, Cu and As concentrations were 124, 144 and 21 $\mu\text{g/g}$. At a site 18 km south-west of Copper Cliff, concentrations of these metals were 57, 58 and 6.2 $\mu\text{g/g}$ respectively.

Concentrations of Zn, Pb and Co did not appear to be related to distance from the smelter.

Concentrations of Heavy Metals in Vegetation

Concentrations of heavy metals in vegetation have been determined at the same sites as for soil samples (above). Data for white birch foliage are shown in Table 5.2.2-4. The relationships of metal concentrations with distance are very similar to those observed in soils, with the exception of Se, which does not appear to be elevated near the smelter in vegetation. Maximum concentrations of metals in white birch foliage (84 $\mu\text{g/g}$ Ni, 35 $\mu\text{g/g}$ Cu, 3.9 $\mu\text{g/g}$ As, 0.60 $\mu\text{g/g}$ Se, 270 $\mu\text{g/g}$ Zn, 10 $\mu\text{g/g}$ Pb, 4 $\mu\text{g/g}$ Co) were generally much less than in soils, with the exception of Zn where concentrations in soil were 2-10 times less than in vegetation.

As for soils, concentrations of Ni, Cu and As in vegetation are probably significantly influenced by emissions from Copper Cliff.

5.2.5 Hudson Bay Mining and Smelting - Flin Flon

5.2.5.1 Aquatic Environment

Concentrations of heavy metals in water

Although several publications provide data on heavy metal concentrations in lakes in the Flin Flon area, the most extensive data set is included in Van Loon and Beamish (1977 - Ref. M11). These data, shown in Table 5.2.5-1, are generally corroborated by corresponding data in Ref. M9, M10 and M22.

Concentrations of zinc were commonly over 100 µg/L within 6 Km of the smelter but approach background levels ($\leq 1-5$ µg/L) at distance of about 15 km. Copper concentrations, up to 23 µg/L near the smelter, were also close to background (1-2 µg/L) at 15 km distance. Cadmium concentrations were also elevated near the smelter (up to 1 µg/L), compared to background levels of ≤ 0.2 µg/L.

Data on other metals are generally lacking. However Van Loon and Beamish (1977 - Ref. M11) say that mercury, arsenic and lead were analysed for (not reported), but that "values were very low or showed no trend". Iron data which were presented also showed no trend with distance.

Concentrations of heavy metals in sediment

Concentrations of Zn, Cu, Cd, Pb, As and Hg in sediments from five lakes in the Flin Flon area were presented in McFarlane and Franzin (1980 - Ref. M9). These are shown on Table 5.2.5-2.

The concentrations of Zn, Cu, Cd, As and Hg were all substantially greater at the three lakes within 9.5 km of the smelter than at the two more distance lakes (12.5, 20 km) with the exception of a high value for copper

TABLE 5.2.5-1

CONCENTRATIONS OF Cu, Cd AND Zn IN WATER
FROM LAKES IN THE FLIN FLON AREA¹

Lake	Distance from Smelter (km)	$\mu\text{g/L}$		
		Cu	Cd	Zn
Beaverdam	3.5	23	1	450
Lake 6	5.0	12	0.5	150
Lake 5	5.0	13	0.5	110
Douglas	5.0	8	0.3	60
Cliff	5.3	10	0.4	85
Whitehead	5.3	10	0.5	150
Hamell	5.8	11	0.6	300
Channing	6.3	2	≤ 0.2	25
Phantom	7.3	5	0.3	55
Lake 4	8.0	10	0.6	50
Lake 3	8.0	8	0.4	50
Embury	8.2	10	0.4	50
We	11.0	6	0.2	15
Wonderland	11.0	6	≤ 0.2	18
Johnson	12.0	3	0.2	10
Little Spruce	12.0	3	≤ 0.2	5
Nesootae	12.5	8	≤ 0.2	30
Mosher	15.0	4	≤ 0.2	17
Scottie	15.0	1	≤ 0.2	2
Bluenose	17.0	2	≤ 0.2	5
Kisseynew	20.0	1	≤ 0.2	1
Neso	24.0	2	≤ 0.2	1
Twin	30.0	1	≤ 0.2	5
Naosap	30.0	2	≤ 0.2	7
Maskunow	33.0	≤ 1	≤ 0.2	1
Otter	33.5	2	≤ 0.2	4
Maligne	50.0	2	≤ 0.2	1
Winteringham	70.0	≤ 1	≤ 0.2	1

¹ From VanLoon and Beamish, 1977 (Ref M11); samples filtered (0.45 μm).

TABLE 5.2.5-2

CONCENTRATIONS OF HEAVY METALS IN THE
LAKE SEDIMENTS IN THE FLIN FLON AREA¹

Lake	Distance from Smelter (km)	$\mu\text{g/L}$					
		Zn	Cu	Cd	Pb	As	Hg
Cliff	5.3	803	174	4.5	72	22	0.4
Hamell	5.8	1986	442	16	274	72	1.16
Hook	9.5	987	242	6	131	39	0.53
Nesootao	12.5	110	29	0.8	24	8.6	0.06
Thompson	20	133	188	0.75	225	4.9	0.09

¹ From McFarlane and Franzin, 1980 (Ref. M9)

in Thompson Lake. Hamell Lake has been most affected by atmospheric metal deposition (1986 $\mu\text{g/g}$ Zn, 442 $\mu\text{g/g}$ Cu, 16 $\mu\text{g/g}$ Cd, 274 $\mu\text{g/g}$ Pb, 72 $\mu\text{g/g}$ As, 1.16 $\mu\text{g/g}$ Hg). Metal concentrations of Nesootao Lake (9.5 km away) were higher than those at Cliff Lake (5.3 km), but this may be because Nesootao is aligned with the prevailing NW-SE wind direction whereas Cliff Lake is northeast of the smelter. However variation from expected distance relationships can also result from mineralogical differences between drainage basins.

Concentrations of Pb, Mn and Fe did not appear to be related to distance from the smelter.

Concentrations of heavy metals in aquatic macrophytes

Concentrations of Zn, Cu, Cd, Pb and As in samples of Myriophyllum exalbens from six Flin Flon area lakes are provided in Ref. M15 (see Table 5.2.5-3). Macrophytes from all lakes within 12.5 km of the smelter had much higher concentrations of metals (except Cu) than from Thompson Lake (20 km away). However the correlation of metal concentration in Myriophyllum with distance or with sediment concentrations was generally poor.

This was thought to be due to the different calcium concentrations in the lake waters and the modifying effect calcium has on the uptake of heavy metals. Metal uptake by macrophytes and other aquatic biota is reduced at higher calcium concentrations.

Concentrations of heavy metals in fish

McFarlane and Franzin (1980 - Ref. M9) have reported concentrations of Cu, Cd and Hg in livers of northern pike and Cd in livers of white sucker from five area lakes (Table 5.2.5-4). No clear relationship between distance from the smelter and metal concentration was found. However, the authors

TABLE 5.2.5-3

CONCENTRATIONS OF Zn, Cu, Cd, Pb AND As
IN SUBMERGED LEAVES AND STEMS OF MYRIOPHYLLUM EXALBESCENS
FROM FLIN FLON AREA LAKES¹

Lake	Distance from Smelter (km)	µg/g (dry wt.)					Ca in Lake Water (mg/L)
		Zn	Cu	Cd	Pb	As	
Lake 6	5.0	12300	346	31	242	263	15.0
Cliff	5.3	1380	90	10	20	48	16.2
Hamel	5.8	1790	54	7	44	40	14.9
Hook	9.5	848	21	4	15	13	38.8
Nesootao	12.5	1470	75	9	24	32	10.0
Thompson	20.0	185	80	1	4	4	14.7

¹ From Franzin and McFarlane, 1979 (Ref. M15)

TABLE 5.2.5-4

MEAN CONCENTRATIONS OF Cd, Cu AND Hg IN FISH LIVERS
FROM FLIN FLON AREA LAKES (RANGE IN BRACKETS)¹

Lake	Distance From Smelter (km)	n ²	µg/g (dry wt.)			
			Northern Pike Cd	Cu	Hg	White Sucker Cd
Cliff	5.3	23(17)	3.3 (1.2-12.0)	58 (20-100)	0.24 (0.06-0.72)	10.1 (2.6-23.5)
Hamell	5.8	18(16)	2.4 (1.1-7.6)	84 (42-301)	0.20 (0.08-0.86)	3.3 (1.4-9.2)
Hook	9.5	19(19)	0.7 (0.1-2.9)	34 (10-97)	0.13 (0.07-0.28)	1.6 (0.2-4.7)
Nesootao	12.5	14(18)	1.8 (0.1-7.3)	67 (27-200)	0.28 (0.11-0.56)	4.4 (2.3-9.8)
Thompson	20.0	17(23)	0.4 (0.1-1.0)	75 (26-180)	0.23 (0.09-0.64)	0.9 (0.4-1.7)

¹ McFarlane and Franzin, 1980 (Ref. M9)² Bracketed number is n for suckers

indicated that the results can be partially explained by an inverse relationship between Ca concentration in the water and liver metal accumulation which has been demonstrated in other studies.

Concentrations of Cd in liver increased with age in both pike and suckers, while Cu and Hg increased with age only in pike (data for suckers not provided). Concentrations of Cd were higher in suckers than in pike in all lakes.

Effects of heavy metals on fish

Two studies have examined the effects of heavy metal pollution on fish populations in Flin Flon area lakes. In the lakes examined, the pH is greater than 7 so that fish are not exposed to low pH stress.

Van Loon and Beamish (1977 - Ref. M11) fished seven lakes having high Zn concentrations (50 - 300 µg/L) with variable-mesh gillnets and obtained data on length, weight, age, and ovary condition from captured fish. Fish communities in all of these lakes were not noticeably affected by heavy metals in terms of fish species presence, abundance, age structure or growth.

Subsequent investigations in the most polluted of these lakes however (Hamell Lake - 300 µg/L Zn, 11 µg/L Cu, 0.6 µg/L Cd) revealed that spawning success of white suckers (Catostomus commersoni) was being seriously impaired. Compared with an "unaffected" population in Thompson Lake, Manitoba, the Hamell Lake suckers showed increased growth, increased fecundity and earlier age of maturation, but reduced spawning success, reduced larval and egg survival, smaller egg size and reduced longevity. At least 50% of mature female suckers in Hamell Lake resorbed their eggs and did not spawn (Ref. M10).

McFarlane and Franzin (1978 - Ref. M10) also indicated that lake herring have apparently disappeared from Hamell Lake and that there have been definite declines in walleye and lake whitefish populations since 1973. These declines occurred during an increase in lake heavy metal concentrations.

5.2.5.2 Terrestrial Environment

Concentrations of heavy metals in soils

Surveys of heavy metal concentrations in soil in the Flin Flon area have been limited to Cu, Pb, Zn and Hg and have been carried out in conjunction with vegetation surveys.

Hogan and Wotton (1983 - Ref. M27) provide data on Cu, Pb and Zn at four soil depths and at distances of 5.8 - 68.2 km from the smelter (Table 5.2.5-5). Concentrations of these metals in the surface organic layer (LFH) were very high within 9 km and greater than background up to 38 km from the smelter. Deeper soil layers had elevated concentrations within 15 km of the smelter.

Concentrations of Hg and Pb in soils (LFH) are presented in McEachern and Phillips (1983 - Ref. M26). Many of the sites sampled were the same as in Ref. M27 and the Pb concentrations found during the two surveys are similar. The Hg results are shown in Table 5.2.5-6. Mercury concentrations were high (to 24 µg/g) within 6 km of the smelter and appeared to be elevated even at a distance of 20 km (1.4 µg/g) compared to the "background" site, located 39 km away (0.4 µg/g).

Concentrations of heavy metals in soil at different distances from the smelter are shown graphically in Figures 5.2.10-1 to 5.2.10-7.

Concentrations of heavy metals in vegetation

Shaw (1981 - Ref. M6) presents concentration of 28 elements, including As, Hg, Pb, Se, Zn and Cu, in berries, leaves and small stems of blueberry

TABLE 5.2.5-5

MEAN CONCENTRATIONS OF Cu, Pb AND Zn IN SOILS
AT DIFFERENT DEPTHS IN THE FLIN FLON AREA¹

Distance (km) and Direction from Smelter	µg/g											
	LFH ²	0-5 cm	5-10 cm	10-15 cm	LFH ²	0-5 cm	5-10 cm	10-15 cm	LFH ²	0-5 cm	5-10 cm	10-15 cm
5.8	1500	520	150	90	800	380	75	25	7400	1200	420	260
5.8	1200	1030	490	300	500	730	390	210	6200	3200	1900	1300
8.9	1100	120	50	70	1100	50	10	6	4600	300	180	140
14.6	500	70	50	70	590	25	20	9	1500	230	130	100
15.5	330	20	30	20	390	10	8	11	1300	70	100	90
35.2	100	60	80	120	200	6	3	2	530	80	80	80
38.1	80	50	60	50	100	6	6	6	280	80	80	80
68.2	30	40	40	60	30	10	10	10	100	100	80	90

¹ From Hogan and Wotton, 1983 (Ref. M27)

² Surface organic layer

TABLE 5.2.5-6

CONCENTRATIONS OF Hg IN THE SURFACE ORGANIC LAYER (LFH)
OF SOILS IN THE FLIN FLON AREA¹

Distance (km) and direction from Smelter	$\mu\text{g/g}$	
	1980	1981
2.0 N-NE	7.80	17.80
4.6 N-NE	4.33	4.38
3.2 NE-E	5.36	6.45
3.7 E-SE	8.54	22.00
5.1 E-SE	7.64	10.20
8.9 E-SE	2.06	12.40
15.5 E-SE	1.05	3.21
38.9 E-SE	0.37	0.43
2.5 SE-S	10.00	17.80
5.8 SE-S	24.00	11.70
19.6 SE-S	1.36	1.43

¹ From McEachern and Phillips, 1983 (Ref. M26)

(Vaccinium myrtilloides), bog cranberry (V.vitis-idaea) and bearberry (Arctostaphylos uva-ursi) from three areas located 2.4 - 36.2 km southeast of the smelter. These data are shown in Table 5.2.5-7; concentrations in leaves (not shown) were almost always intermediate between berries and stems. The concentrations of each of the six metals shown in this table are markedly elevated near the smelter. Concentrations of Zn (to 2640 µg/g) were particularly high. Mercury concentrations in blueberries at the nearest site (approx. 0.07 µg/g wet weight, assuming 70% water content as in Ref. M26) are above the maximum dietary concentration as published by the Food and Nutrition Board of the National Research Council of Canada (0.05 µg/g wet wt.). The latter value was also exceeded at five locations in a survey of mercury and lead in blueberries (Ref. M25) but not in a more recent survey (Ref. M26). Blueberries within 5 km of the smelter contained 20-30 times as much lead as the national average (0.05 µg/g wet wt.) in one survey (Ref. M26).

Hogan and Wotton (1983 - Ref. M27) measured Cu, Pb and Zn in foliage of jack pine, black spruce, alder and Labrador tea at eight sites located 5.8 to 68.2 km from the smelter. Concentrations were inversely related to distance. The range of values (e.g. for jack pine : 3 - 29 µg/g Cu, 5-62 µg/g Pb, 75-506 µg/g Zn) do not contain the very high concentrations which occurred at the nearest site in Shaw's (1981 - Ref. M6) survey (Table 5.2.5-7), but still indicate levels near the smelter to be about 10 times background levels.

Concentrations of heavy metals in animals

Kucera (1983 - Ref. M17) measured concentrations of As, Zn, Cu, Ni, Co and Pb in hides and carcasses of deer mice (Peromyscus maniculatus) from areas 4 - 185 km from the smelter (Table 5.2.5-8).

TABLE 5.2.5-7

CONCENTRATIONS OF As, Hg, Pb, Se, Zn AND Cu
IN BERRIES AND SMALL STEMS OF
BLUEBERRIES, BEARBERRIES AND BOG CRANBERRIES IN THE FLIN FLON AREA

µg/g (dry wt.)

Distance from Smelter (km)	Species												
		As		Hg		Pb		Se		Zn		Cu	
		b ²	S	b	S	b	S	b	S	b	S	b	S
2.4	Blueberry	2.01	13.0	0.22	1.09	7.26	146.0	0.22	1.18	164	955	21.1	139
	Bearberry	1.12	7.69	0.07	1.45	0.04	51.6	≤0.03	0.71	44	1190	4.7	87.9
	Cranberry	3.68	18.1	0.46	1.16	23.5	171.0	0.28	1.84	263	2640	44.4	315
26.5	Blueberry	0.31	1.52	0.01	0.09	0.10	39.7	≤0.03	0.29	23	423	3.7	35.4
	Bearberry	0.10	0.65	≤0.01	0.05	0.03	11.9	≤0.03	0.05	24	268	4.3	9.8
	Cranberry	0.30	0.79	0.03	0.05	0.14	14.1	≤0.03	0.05	32	103	4.3	7.7
36.2	Blueberry	0.16	0.02	0.02	0.26	0.03	24.9	0.07	0.23	17	124	3.7	16.4
	Bearberry	0.07	0.37	≤0.01	0.03	0.02	9.16	≤0.03	0.04	19	178	3.6	8.4
	Cranberry	0.27	1.31	0.02	0.04	0.07	17.3	0.03	0.23	18	166	4.2	13.9

¹ From Shaw (1981) (Ref. M6)² b = berries; S = small stems

TABLE 5.2.5-8

MEAN CONCENTRATIONS OF As, Zn, Cu AND Pb IN DEER MICE
AT VARIOUS DISTANCES FROM THE FLIN FLON SMELTER¹

Distance from Smelter (km)	$\mu\text{g/g}$ (ash wt.)			
	As (hide)	Zn (hide)	Cu (hide)	Pb (carcass)
4	1.54	133	14.6	13.8
11	0.92	113	11.4	8.0
37	0.26	141	10.0	3.1
61	0.37	117	9.0	3.2
185	0.20	102	9.4	5.3

¹ From Kucera (1983) (Ref. M17)

Nickel was not detected in any of the samples and Co values were similar at all distances. Arsenic and Pb concentrations were distinctly higher within 11 km of the smelter and Cu was slightly higher. Zinc concentrations appeared to be little affected by smelter emissions.

Effects of heavy metals on vegetation

Within 5 km of the smelter, the vegetation has been severely degraded in terms of tree die-off, reduced growth and reduced species diversity by sulphur dioxide and heavy metal emissions. These effects diminish with distance but are still detectable at about 15 km from the smelter (Ref. M24).

Wotton et al (1983 - Ref. M24) carried out a detailed vegetation inventory of 8 mixed forest stands located 5.1 - 68.2 km from the smelter in 1978 and reevaluated the sites in 1983. They found that sites within 6 km had higher tree mortality, reduced living tree basal area and reduced understory and shrub layers. The abundance of mosses and lichens increased with distance from the smelter.

Effects of heavy metals on animals

Hemoglobin concentrations in deer mice were found to be elevated within 40 km of the smelter (compared to background), although they were still within the normal range reported in the literature. Mean concentrations 4-6 km from the smelter were 14.6 g/100 mL (range 7.0 - 19.9) compared to 13.5 g/100 mL (6.8 - 16.7) in mice living 61-68 km away (Ref. M17). These data suggest that a physiological response to higher metal concentrations in the diet may be occurring.

Kucera (1983 - Ref. M17) trapped deer mice and red-backed voles (Clethrionomys gapperi) at distances of 4, 11, 37, 61 and 185 km from the smelter.

Although the red-backed vole is usually the most common small mammal in the boreal forest in the Flin Flon area, it was not captured at the site located 4 km away and was less abundant than deer mice up to 37 km away. It was suggested that reduced vole abundance resulted from elevated concentrations of heavy metals in the environment. Voles, being largely herbivorous, would ingest more metals than the granivorous mice. Vole populations also appeared to be reduced near the Inco smelter at Thompson.

5.2.6 Noranda - Horne

5.2.6.1 Aquatic Environment

Concentrations of heavy metals in sediments

Although heavy metal concentrations in sediments have been determined for a large number of waterbodies in the Rouyn-Noranda area (Ref. Q13), most sites were located where inputs of heavy metals from mining/smelting facilities are occurring or have occurred by surface drainage pathways. After careful review, it appeared that only four of the waterbodies were located such that they would receive heavy metals only as a result of atmospheric deposition. The data for these waterbodies are shown in Table 5.2.6-1.

It can be seen that concentrations of heavy metals (As, Hg, Cd, Cu, Pb, Zn) were not extremely high in any of the waterbodies, although some contamination is apparent. Sediments in the stream closest to the smelter (4 km away) had the highest concentrations of each of the metals. However, only Cd (11 µg/g) and Pb (71 µg/g) levels were much above regional background (Cd - ≤0.2 µg/g; Pb - ≤1-10 µg/g).

Concentrations of heavy metals in water

Most water quality stations described in Reference Q13 (Project "Region Rouyn-Noranda", Groupe "Ecologie", Final Report, 1979) receive contaminated water from active mining or smelting activities or, to a lesser extent, from old mine sites or tailings areas. Concentrations of As, Cd, Cu, Hg, Pb and Zn in waterbodies which receive only atmospheric inputs are shown in Table 5.2.6-2. Relatively high concentrations of Hg (max. 0.37 µg/L) and, to a lesser extent, copper (max. 18 µg/L) were found in some lakes. However, the concentrations of other metals did not appear to be elevated. In addition to the June, 1978 data shown in Table 5.2.6-2, data for February, May and

TABLE 5.2.6-1

**MEAN CONCENTRATIONS OF HEAVY METALS IN SEDIMENTS
OF SELECTED SURFACE WATERS IN THE ROUYN - NORANDA AREA¹**

Water Body	Avg. Distance from smelter (km)	$\mu\text{g/g}$					
		As	Hg	Cd	Cu	Pb	Zn
Ruisseau Heré	4	5	0.13	11	85	71	143
Rivière Hélène	9	2	0.05	-	56	63	83
Ruisseau Grance	14	2	0.06	-	31	38	140
Lac Montbeillard	18	3.6	0.027	1.3	36	26	103
Regional background		0.5-1.5	0.02- 0.09	≤ 0.2	15- 40	≤ 1 - 10	60 - 120
Concentrations suggesting contamination		≥ 10	≥ 0.1	≥ 3	≥ 100	≥ 50	≥ 200

¹ from Bureau d'Etude sur les Substances Toxiques, 1979 (Ref. Q13)

TABLE 5.2.6-2

CONCENTRATIONS OF HEAVY METALS IN SELECTED SURFACE WATERS
IN THE ROUYN - NORANDA AREA, JUNE 1978¹

Lake	Distance (km) and direction from smelter		µg/L					
			As	Cd	Cu	Hg	Pb	Zn
Héré	4.4	WNW	≤20	0.6	18	0.02	7	≤20
Adéline	12	WSW	≤20	≤0.5	5	0.06	≤2	20
Hélène	13	WSW	≤20	0.5	13	0.19	≤2	20
Duprat	13	NW	≤20	1.7	11	0.37	2	30
Montbeillard	19	SSW	≤20	0.5	6	0.03	4	20
Fréchette	30	SSW	≤20	0.5	5	0.03	4	30
Acceptable limit for aquatic life ¹			10	4	5-10	0.2	25-1300	30-1000
Objective ¹			ND	ND-4	ND ²	ND-0.05	30	10-50

¹ from Bureau d'Etude sur les Substances Toxiques, 1979 (Ref. Q13)

² not detectable

and August, 1978 are also available for Lacs Duprat and Montbeillard and for May and August, 1978 at Lac Frechette (Ref. Q13). Concentrations in these sets of analyses were generally similar to those in June samples with the exception of Hg, where concentrations ranged from $\leq 0.05 - 0.22 \mu\text{g/L}$ in Lac Montbeillard and $0.07 - 0.08 \mu\text{g/L}$ in Lac Frechette. Elevated concentrations of Hg have been found in snow near Lac Montbeillard (Ref. Q13).

Concentrations of heavy metals in fish

Heavy metal concentrations in several fish species from two lakes affected only by atmospheric deposition are shown in Table 5.2.6-3. Except for Hg, these concentrations were considered to be relatively low, similar to values in the St. Lawrence River (Ref. Q13). Two out of eight walleye in Lac Duprat and 7 of 13 pike and 3 out of 10 walleye in Lac Montbeillard had Hg concentrations greater than that considered safe for human consumption ($0.5 \mu\text{g/g}$ wet wt).

Effects of heavy metals on plankton

Studies have been conducted on the toxicity of water from a number of Rouyn-Noranda area lakes and rivers, including Lac Duprat and Lac Montbeillard, to an algal species (Selenastrum capricornutum) and a crustacean zooplankton species (Daphnia magna). Lac Duprat water, which contained up to $13.7 \mu\text{g/L}$ Cu and $0.37 \mu\text{g/L}$ Hg, was found to be slightly toxic to both species (reduced algal growth; inhibition of Daphnia mobility). No significant toxic effects were detected in Lac Montbeillard water (max. $9 \mu\text{g/L}$ Cu, $0.22 \mu\text{g/L}$ Hg).

5.2.6.2 Terrestrial Environment

Concentrations of heavy metals in soil

The only soils data found consisted of concentrations of six metals in 18 samples of LFH (surface organic layer), all collected from an area located

TABLE 5.2.6-3

MEAN CONCENTRATIONS OF HEAVY METALS IN FISH FLESH FROM TWO LAKES
IN THE ROUYN - NORANDA AREA 1978, RANGE IN BRACKETS¹

Fish Species	n	As	Cd	$\mu\text{g/g}$			
				Cu	Pb	Zn	Hg
				<u>Lac Duprat</u>			
Pike	10	-	≤ 0.04 (≤ 0.04 -.04)	0.39 (.30-.48)	0.10 (.04-.17)	11.4 (7.8-16.8)	0.15 (.08-.25)
Perch	5	-	0.09 (.08-.10)	0.76 (.42-1.10)	0.14 (.10-.18)	15.8 (13.4-18.2)	0.12 (.07-.15)
Walleye	8	-	0.06 (.04-.08)	0.55 (.44-.80)	0.08 (.04-.15)	6.4 (5.0-8.2)	0.28 (.07-.74)
Cisco	3	0.06 (.03-.08)	0.13 (.10-.14)	0.75 (.52-.96)	0.08 (.07-.09)	12.2 (9.6-14.8)	0.12 (.04-.22)
				<u>Lac Montbeillard</u>			
Pike	13	0.04 (ND-.12)	0.05 (≤ 0.04 -.10)	0.32 (.24-.60)	0.09 (.04-.21)	8.8 (4.8-12.4)	0.54 (.22-1.34)
Perch	7	0.02 (ND-.06)	0.16 (.12-.18)	0.35 (.24-.48)	0.14 (.07-.18)	9.6 (6.8-12.8)	0.26 (-.87)
Walleye	10	0.01 (ND-.05)	0.13 (.04-.24)	0.39 (.32-.56)	0.10 (.08-.15)	8.7 (5.2-12.4)	0.42 (.08-.84)
Sauger	1	≤ 0.03	-	-	-	-	0.48

¹ from Bureau d'Etudes sur les Substances Toxiques, 1979 (Ref. Q13)

2-3 km south-east of the smelter. Mean concentrations (range in brackets) in $\mu\text{g/g}$ dry weight were as follows (Ref. Q13):

Cu	-	6400	(3000-15,000)
Zn	-	980	(560- 2,500)
Pb	-	2300	(1000- 4000)
As	-	190	(125- 255)
Cd	-	63	(20- 95)
Hg	-	0.217	(0.085-0.375)

Although no background concentrations from the Rouyn-Noranda area were provided, it is readily apparent that concentrations of all metals with the exception of Hg in this area are very high. Typical background concentrations from Sudbury area studies are as follows (in $\mu\text{g/g}$): Cu (6-11); Zn (25-38); Pb (8-17); As (1.8-2.2) (Ref. 046). Background Cd concentrations in Manitoba are in the order of 0.3 $\mu\text{g/g}$ (Ref. M14). Concentrations of Hg in soil are generally less than 1 $\mu\text{g/g}$.

Concentrations of heavy metals in vegetation

Mean concentrations (and ranges in brackets) of heavy metals in foliage of 7 samples of trembling aspen and 4 samples of paper birch collected from the same area as the soil samples are shown in Table 5.2.6-4. The data shown in this table are for foliage which did not have visible signs of SO_2 damage. There was no significant difference in concentrations of heavy metals in injured and uninjured foliage.

The concentrations of Cu, Pb, Zn and Cd were all 5-10 times greater than typical background levels. Mercury concentrations do not appear to be particularly high, but local background levels are required for a meaningful assessment.

TABLE 5.2.6-4

MEAN CONCENTRATIONS OF HEAVY METALS IN FOLIAGE
OF TREMBLING ASPEN AND PAPER BIRCH
2-3 km SOUTH-EAST OF THE NORANDA SMELTER¹

Species	$\mu\text{g/g}$ (dry wt.)				
	Cu	Pb	Zn	Cd	Hg
Trembling aspen	36 (26-51)	88 (38-180)	1280 (730-2630)	15 (9-21)	0.05 (.03-.08)
Paper birch	38 (33-47)	76 (50-123)	1230 (820-1430)	8 (5-9)	0.07 (.06-.09)
Typical background concentrations	7 ²	5-6 ²	270-380 ²	≤ 1	.01-0.2

¹ from Bureau d'Etude sur les Substances Toxiques 1979 (Ref. Q13); only data for foliage undamaged by SO₂ emissions are shown; range in brackets.

² in paper birch from studies conducted in the Sudbury area (Ref. 046).

Concentrations of heavy metals in wildlife

Concentrations of heavy metals were measured in muscle and liver of snowshoe hare and ruffed grouse collected at sites 4-21 km from the smelter. The data are shown on Table 5.2.6-5. The results were highly variable and the numbers of samples were small, making interpretation difficult. However it appears that Cd and Cu levels in hare liver were distinctly elevated at the site 4 km from the smelter (10.5 $\mu\text{g/g}$ Cd, 28.7 $\mu\text{g/g}$ Cu).

5.2.7 Noranda - Murdochville

No information has been received on the environmental effects of atmospheric heavy metal emissions from this smelter.

5.2.8 Brunswick Mining and Smelting - Belledune

5.2.8.1 Aquatic Environment

The only investigations into the effects of atmospheric heavy metal deposition in the aquatic environment of which we are aware consisted of analyses of heavy metals in the Jaquet River and in river sediments. Most aquatic studies at Belledune have been concerned with Belledune Harbour, which is affected primarily by liquid effluents.

Concentrations of heavy metals in water

Concentrations of Cd, Cu and Zn in the Jaquet River (19 km from smelter) were less than the limits of detection (Ref. N6).

Concentrations of heavy metals in sediments

Table 5.2.8-1 shows the concentrations of Pb, Zn and Cd in sediments of several rivers which discharge into Chaleur Bay or Nepisiguit Bay. Analyses from watercourses draining areas of known mineral occurrences have been excluded (Ref. N6).

It appears that metal concentrations were slightly elevated for about 6 km south of the smelter. This level of influence corresponds reasonably well with metal concentrations in soils (Table 5.2.8-2). However the sediment data in general were quite variable with respect to distance, possibly resulting from different mineralogical characteristics of the drainage basins.

TABLE 5.2.8-1

**MEAN CONCENTRATIONS OF Pb, Zn AND Cd IN RIVER SEDIMENTS
IN THE VICINITY OF BELLEDUNE IN 1978¹**

River and Number of Sampling Stations	Distance from Smelter (km) ²	µg/g		
		Pb	Zn	Cd
<u>South of Belledune</u>				
Hendry Brook (2)	2	86	185	1.5
Quilford Creek (2)	4	34	175	1.7
Guitar Brook (2)	6	103	266	2.3
Fournier Brook (3)	9	25	111	0.5
Nigadoo River (7)	19	53	141	0.7
Millstream River (5)	23	36	139	0.8
Grants Brook	26	17	108	0.9
<u>West of Belledune</u>				
Belledune River (3)	5	37	157	0.8
Armstrong Brook (3)	12	25	137	1.0
Louison Creek (3)	17	47	135	1.0
Blackland River (2)	30	18	107	0.3

¹ Derived from Hatch Associates, 1981 (Ref. N6)

² Mean distance of sampling stations from smelter

TABLE 5.2.8-2

MEAN CONCENTRATIONS OF Pb, Zn, Cd AND Cu
IN SOILS, 1975-1979 IN THE BELLEDUNE AREA¹

Distance from Smelter (km)	Number of Stations	$\mu\text{g/g}$			
		Pb	Zn	Cd	Cu
0.2 - 0.5	2	1872	9871	25.6	121
0.8	3	590	445	9.1	66
1.4 - 1.8	5	246	264	4.9	52 ²
2.2 - 2.9	4	114	136	2.8	34
7.0 - 8.0	2	82	123	2.1	25
12.8 - 15.4	3	86	127	2.0	39

¹ Derived from Hatch Associates, 1981 (Ref. N6); composite samples 0-15 cm

² One anomalous value (974) excluded

5.2.8.2 Terrestrial Environment

Concentrations of heavy metals in soils

Mean concentrations of Pb, Zn, Cd and Cu in soils at various distances from the smelter during 1975-1979 are shown in Table 5.2.8-2 and Figures 5.2.10-1 to 5.2.10-7. Within 0.5 km of the smelter, mean concentrations (1872 µg/g Pb, 987 µg/g Zn, 25.6 µg/g Cd 121 µg/g Cu), were about 20 times background for Pb, 10 times background for Zn and Cd and 5 times background for Cu. For all metals, concentrations appeared to be approaching background at a distance of about 7 km. Average concentrations of Pb and Cd within 1.8 km of the smelter were significantly lower during 1973 - 1976 (Ref. N9).

MacMillan (1981 - Ref. N2) presents data from a number of sites for the years 1966, 1967, 1975, 1980 for 14 metals. The usefulness of the data is greatly reduced because the nearest sites are 7 km from the smelter. However at the 7 km sites, Zn and Pb concentrations in the soil more than doubled between 1967 and 1980 and Zn concentrations also appear to have increased over time at a distance of 15 km and Pb at 10 km. No other consistent trends are apparent. The Pb concentrations reported in this paper are quite low compared to those in Ref. N6 and N9.

Concentrations of heavy metals in vegetation

Concentrations of Pb, Cu, Zn and Cd in forage (grass), lettuce and potatoes at various distances from the smelter are shown in Table 5.2.8-3. Metal concentrations in lettuce and potatoes, with the exception of Pb in lettuce, were well below those identified in the Canadian Food and Drug Regulations with regard to fresh vegetables (µg/g fresh wt: 2.0 Pb, 50.0 Zn, 50.0 Cu, 1.0 Cd) and generally did not show clear relationships with distance from the smelter. Average lead levels in lettuce near the smelter (4.0 - 7.2 within 8 km) were greater than these regulations.

TABLE 5.2.8-3

MEAN CONCENTRATIONS OF Pb, Cu, Zn AND Cd
IN LETTUCE, POTATOES AND FORAGE (GRASS)
AT HARVEST IN THE BELLEDUNE AREA, 1972-1975¹

Distance from Smelter (km)	Number of Sampling Sites	$\mu\text{g/g}^2$			
		Pb	Cu	Zn	Cd
Forage	0-0.8	1722	77	540	34
	1.0-1.6	320	12	165	6
	1.7-3.2	274	15	177	4
	3.3-8.0	119	6	113	3
	8.1-16	81	6	88	1
	16-38	28	4	39	1
Lettuce	1.7-3.2	7.2	0.9	7.7	0.2
	3.3-8.0	4.0	0.5	4.2	0.18
	8.1-16	0.7	2.5	8.7	0.2
	≥ 16	0.4	0.9	2.8	0.05
Potatoes	1.7-3.2	0.4	1.1	4.5	0.06
	3.3-8.0	0.7	1.9	1.8	0.06
	8.1-16	1.3	0.4	3.9	0.06
	≥ 16	1.3	0.6	4.2	0.07

¹ From Dugdale and Hummell, 1977 (Ref. N9)

² (Concentrations in $\mu\text{g/g}$ dry wt. for forage and $\mu\text{g/g}$ fresh wt. for lettuce and potatoes; lettuce and potatoes washed)

Concentrations of all metals in forage were very high within 0.8 km of the smelter and Pb and Zn did not appear to approach background levels until more than 16 km distant from the smelter; Cu and Cd concentrations were close to background beyond 8 km. Concentrations of Pb in forage as low as 80 $\mu\text{g/g}$ may be toxic to horses (in Ref. N9), which are particularly sensitive to Pb contamination.

5.2.9 Cominco - Trail

5.2.9.1 Aquatic Environment

No information on heavy metals in the aquatic environment relevant to the present study have been found. Although some Hg data are presented in Garrett et al (1980 - Ref. G18), these pertain to the effects of liquid effluents.

5.2.9.2 Terrestrial Environment

Concentrations of Heavy Metals in Soil

Data concerning the concentrations of heavy metals in soil in the vicinity of Trail have been summarized in the Kootenay Air and Water Quality Study, Phase 1 (1977 - Ref. B12) and are shown in Table 5.2.9-1. These data are fairly old since, with the possible exception of the Archibold analyses, all samples were collected during or prior to 1972.

It is apparent that there has been considerable contamination of soils in the Trail area since mean concentrations of Pb (657 - 2607 $\mu\text{g/g}$), Zn (571 $\mu\text{g/g}$) and Cd (17.1 $\mu\text{g/g}$) in surface layers are all very high. Deeper soil layers (5-10 cm) have also been affected, but to a much lesser extent. Copper concentrations in soil (12-107 $\mu\text{g/g}$) may be slightly elevated; background levels of Cu in soil are 20-100 $\mu\text{g/g}$ (Table 5.2.1-2).

Lead levels in soil at distances of 0.4 - 96 km from the smelter are shown in Table 5.2.9-2.

TABLE 5.2.9-1

CONCENTRATIONS OF Pb, Zn, Cd AND Cu IN SOILS NEAR TRAIL¹

Source Sample Depth	µg/g					Warren (⁵) Top 15-20 cm	Typical Background Levels in B.C. ¹
	John (²) 0-5cm	John (²) 5-10cm	Archibold (³) 0-15cm	Schmitt (⁴) 0-2.5cm	Schmitt (⁴) 2.5-17.5cm		
Pb							
Range	291-12,123	12-1,002	265-2,950	22-4,200		7,500	- 180
Mean	2,607	194	1,127	657	194		10.6
n*	15	15	20	15		7	
Zn							
Range	135-1,394	38-391				76-1,520	-
Mean	571	148					(105)
n*	15	15				7	
Cd							
Range	1.8-33.8	0.1-21.5					-
Mean	17.1	5.6					0.9
n*	15	15					
Cu							
Range						12-107	
n*						7	

¹ from Kootenay Air and Water Quality Study, Phase 1, 1977 (REF. B12)² John et al, 1975; 15 sites, 13 of which were within 3 km of smelter.³ Archibold unpub. thesis, 1974; intervals of 1.5 km north and south of smelter.⁴ Schmitt et al, 1971; sites located 0.4 - 96 Km from smelter.⁵ Warren et al, 1971 and pers. comm., 1977; sites approx. 3 km north of smelter.

* sample size

Concentrations of Heavy Metals in Vegetation

Lead levels in soils and grass samples collected at various distances from the smelter during 1969 are shown in Table 5.2.9-2. Concentrations were found to be very high within one kilometer of the smelter (max. 4200 $\mu\text{g/g}$ in soil, 264 $\mu\text{g/g}$ in grass) but were near background levels at distances greater than 6 km.

Lead concentrations were also measured in a wide variety of fruits, garden vegetables and herbs within 8 km of the smelter. These were generally considered to be acceptable as human food, although high concentrations were found in several herbs (mint, basil, endive, parsley, sage) (Ref. B19). In the same study, high levels of Zn in grass were found near the smelter (275-1100 $\mu\text{g/g}$; up to 3500 $\mu\text{g/g}$ in overwintered grass). Levels of Zn, Cd and As in garden vegetables (Table 5.2.9-3) were not considered to be excessive with the exception of Zn and As in mint samples at one site (273 $\mu\text{g/g}$ Zn, 22.6 $\mu\text{g/g}$ As).

Effects of Heavy Metals on Animals

Schmitt et al (1971 - Ref. B19) conducted detailed investigations into instances of lead toxicity in horses pastured near the smelter. Chronic debilitating disorders in six horses were considered to be a result of the high lead levels in forage (Table 5.2.9-2). Blood lead levels in the debilitated horses were significantly higher than in healthy horses.

TABLE 5.2.9-2

CONCENTRATIONS OF Pb IN SOIL AND FORAGE (GRASS)
AT DIFFERENT DISTANCES FROM THE TRAIL SMELTER, 1969¹

Distance (km) and direction from smelter		$\mu\text{g/g}$ (dry wt.)	
		Soil (top 2.5 cm)	Forage
0.4	N	4200	177
0.8	N	2900	264
2.4	SW	620	90
2.4	S	245	121
3.2	SW	750	38
5.6	SW	45	18
8.0	SW	40	6
9.6	S	370	23
16	E	85	3
18	SE	65	5
21	E	40	4
22	N	280	18
22	S	130	8
38	NE	60	6
96	E	22	2

¹ from Schmitt et al, 1971 (Ref. B19)

TABLE 5.2.9-3

RANGE OF Cd, Zn, As AND Pb CONCENTRATIONS
IN VEGETABLES, TRAIL AREA, 1969¹

	$\mu\text{g/g}$ (fresh wt.)			
	Cd	Zn	As	Pb
Root vegetables	0.01-0.90	1.2-39.3	Nil-7.3	Nil-6.0
Green vegetables (major food items)	Nil-0.6	≤ 0.1 -37.0	Nil-0.19	Nil-16.8
Green vegetables (minor food items excluding mint)	≤ 0.01 -2.5	0.1-103.2	Nil-3.0	0.02-22.50

¹ from Schmitt et al, 1971 (Ref. B19)
samples washed and prepared as for household use

5.2.10 Summary

The effects of the eight smelters on the natural environment, which result from atmospheric deposition of heavy metals, vary according to the composition of the raw materials, the processing and pollution control equipment, and the height of the stack. The data which are available to assess smelter effects are also highly variable, in terms of both quantity and quality. However, despite these differences, it is possible to make some conclusions which are generally applicable to all of the smelters (excluding Noranda-Murdochville, for which no data were available).

- 1) Soils have been heavily contaminated by two or more metals in the vicinity of each of the smelters (within 3 km).
- 2) Heavily contaminated soils have been shown to be toxic to plants, wherever this has been examined. Effects include inhibition of seed germination, reduced seedling survival and growth reduction.
- 3) High concentrations of two or more metals have been found in vegetation around each of the smelters. In some cases, these concentrations represent real or potential animal or human health hazards if affected plant species are eaten regularly (e.g. mercury in blueberries at Flin Flon, lead in forage at Trail). Data on metals in locally grown foods (for humans or domestic animals) however are lacking or very limited with respect to most smelters.
- 4) The few wildlife studies which have been done do not provide sufficient data to accurately assess the impact of smelters on wildlife populations. However the effects which have been noted (some accumulation of metals in body tissues; apparent physiological stress as indicated by increased haemoglobin levels in mice; apparent shift in relative abundance of small mammals) appear to be minor compared to effects on vegetation, soils and the aquatic environment.

- 5) Effects on the aquatic environment have only been studied in some detail in the Sudbury area (Inco and Falconbridge), at Flin Flon and to a lesser extent at Noranda-Horne.
- 6) Where examined, high concentrations of one or more metals from air emissions have been found in surface water, sediments, plankton, macrophytes and fish.
- 7) Where examined, some lake waters affected by air emissions in the vicinity of the smelters have been shown to have toxic effects on fish and plankton due to heavy metal contamination. Both lethal and sublethal effects have been described. The sublethal effects included impairment of fish spawning, reduced plankton biomass and diversity and altered relative plankton species abundance.
- 8) Concentrations of heavy metals in fish flesh have only been determined in the vicinity of one smelter (Noranda-Horne), where it was found that mercury levels were frequently greater than the acceptable limit for human consumption.

The relative abundance of the different metals released to the environment varies considerably from smelter to smelter. This can best be seen from a comparison of metal concentrations in soils near each of the smelters (Table 5.2.10-1). Soils were selected for this comparison because the data are the most complete. Useful water quality data were available only from Sudbury and two other smelters; vegetation data were available from 7 of 8 smelters but there was no consistency in the plant species in which metals were analyzed. Metal concentrations in soils also provide a historical (cumulative) perspective since metals are fairly persistent in soil.

At the nickel smelters in Sudbury and Thompson, the principal metal contaminants are Cu and Ni. At Flin Flon and Noranda-Horne, Cu, Pb and Zn are all

abundant in the surrounding soils, whereas Pb and to a lesser extent Zn represent most of the contamination from the Belledune and Trail smelters.

Several other metals (As, Cd, Hg, Co) are also present in the soils at levels which are much higher than background (see Table 5.2.10-1). Arsenic is present in fairly high concentrations in soils near the Noranda-Horne smelter and to a lesser extent near the nickel smelters. Significant Cd contamination has occurred at Noranda-Horne, Belledune and Trail. High Hg levels have been reported from Flin Flon and Co concentrations are somewhat high near the nickel smelters.

Figures 5.2.10-1 to 5.2.10-7 show the concentrations of heavy metals in soil at various distances from the smelters for those instances where significant contamination has occurred. Data for these Figures are all contained in Tables in Section 5.2.

The remainder of this section summarizes environmental effects at each of the smelters.

Inco and Falconbridge - Sudbury

- . water - Ni and Cu concentrations are significantly higher than background levels within 15-60 km from Sudbury, depending on direction; Zn concentrations are somewhat elevated.
- . sediment - Ni and Cu concentrations are significantly elevated in an area similar to that observed for water.
- . plankton - major differences in plankton communities were shown to be attributable to Cu and Ni toxicity; some phytoplankton species have become adapted to higher metal levels.

- . fish - fish were unable to survive in pH-neutralized lakes due to toxic effects of Cu and possibly Zn, Al and Ni.
- . soil - soils are most heavily contaminated near Coniston; concentrations of Cu and Ni do not approach background levels until about 30+ km from the smelters; Cu and Ni toxicity is reducing leaf litter decomposition and tree seedling establishment.
- . vegetation - Ni and Cu are the main contaminants in terrestrial vegetation; concentrations in lichens are at background levels 60 km from the Copper Cliff smelter (along a NNW transect); regeneration of denuded areas is hindered by soil erosion and metal toxicity.
- . wildlife - concentrations of Ni were three times background levels in grouse tissues near Sudbury.

Inco - Thompson

- . there are no useful data on metals in the aquatic environment.
- . soils - Ni and Cu concentrations are elevated within 40 km of the smelter; As and Co levels are also greater than background within 13.5 km.
- . vegetation - Ni, Cu and Co concentrations in vegetation are about 10-15 times background levels close to the smelter but are near background levels at distance of 25 km, 15 km and 6 km respectively; As and Co are minor contaminants; moss and lichen cover has been reduced within 20 km of the smelter and has been eliminated at many sites within 8 km; soils within 2.3 km of the smelter are toxic to jack pine seedlings.

- . wildlife - Ni and Co concentrations in small mammals are slightly higher near the smelter (4 km); voles appear to be less abundant near the smelter.

Hudson Bay Mining and Smelting - Flin Flon

- . water - Zn and Cu concentrations are elevated due to air emissions within about 15 km of the smelter; Cd concentrations are also slightly elevated.
- . sediment - high concentrations of Zn, Cu, Cd, As and Hg occur in lake sediments within 10 km of the smelter.
- . fish - spawning of suckers has been seriously impaired in a lake containing high concentrations of Zn, Cu and Cd; populations of other species in this lake have declined.
- . soils - concentrations of Cu, Pb and Zn are very high within 9 km of the smelter and are greater than background up to 38 km away; Hg concentrations are high within 6 km of the smelter.
- . vegetation - concentrations of Zn, Pb and Cu in plants are all about 10 times background levels at a distance of 6 km from the smelter; Hg levels in blueberries have exceeded maximum dietary concentrations (0.05 µg/g - Food and Nutrition Board, NRC); vegetation growth is very poor within 5 km of the smelter.
- . wildlife - concentrations of As, Pb and, to a lesser extent, Cu in deer mice were higher than background within 10 km of the smelter; voles were less abundant near the smelter.

Noranda - Horne

- . water - elevated concentrations of Hg and Cu have been found in some lakes.
- . sediments - only one stream had sediments containing metal concentrations (Pb, Cd) much above regional background levels.
- . fish - Hg concentrations greater than safe eating levels were found in two area lakes.
- . soils - soils in an area 2-3 km from the smelter have been heavily contaminated with Cu, Zn, Pb, As and Cd; no other areas were studied.
- . vegetation - metals were analyzed in vegetation from the same area as the soils; Cu, Pb, Zn and Cd concentrations were all 5-10 times higher than typical background levels.
- . wildlife - Cu and Cd concentrations in snowshoe hare were higher than background at a site 4 km from the smelter.

Noranda - Murdochville

- . no data available.

Brunswick Mining and Smelting - Belledune

- . data on heavy metals in the aquatic environment are very limited, although it appears that Pb, Zn and Cd levels are slightly elevated in stream sediments within about 6 km of the smelter.

. soils - Pb and Zn are the principal contaminants, although some Cd and Cu contamination is also present; for all of these metals, concentrations are very high only within 3 km or less of the smelter and are near background levels at 7 km away.

. vegetation - Pb, Cu, Zn and Cd concentrations were measured in forage and garden vegetables; Pb concentrations in lettuce were higher than tolerances identified in Canadian Food and Drug Regulations; concentrations of Pb in forage were greater than levels which can be toxic to horses (80 µg/g) within 8 km of the smelter; high concentrations of Cu, Zn and Cd also occurred in forage.

Cominco - Trail

. no useful data on the effects of heavy metals in the aquatic environment were found.

. soils - available soils data are fairly old (15 years±) but considerable contamination by Pb, Zn and Cd within 3 km of the smelter is apparent.

. vegetation - available data are fairly old, as for soils; very high concentrations of Pb and Zn occurred in grass near the smelter; concentrations of Pb, Zn, Cd and As in garden vegetables were slightly elevated but considered to be acceptable as human food.

. animals - horses pastured near the smelter developed chronic, debilitating disorders due to high Pb concentrations in forage.

Figure 5.2.10-1

Metal Concentrations in Soil-Ni

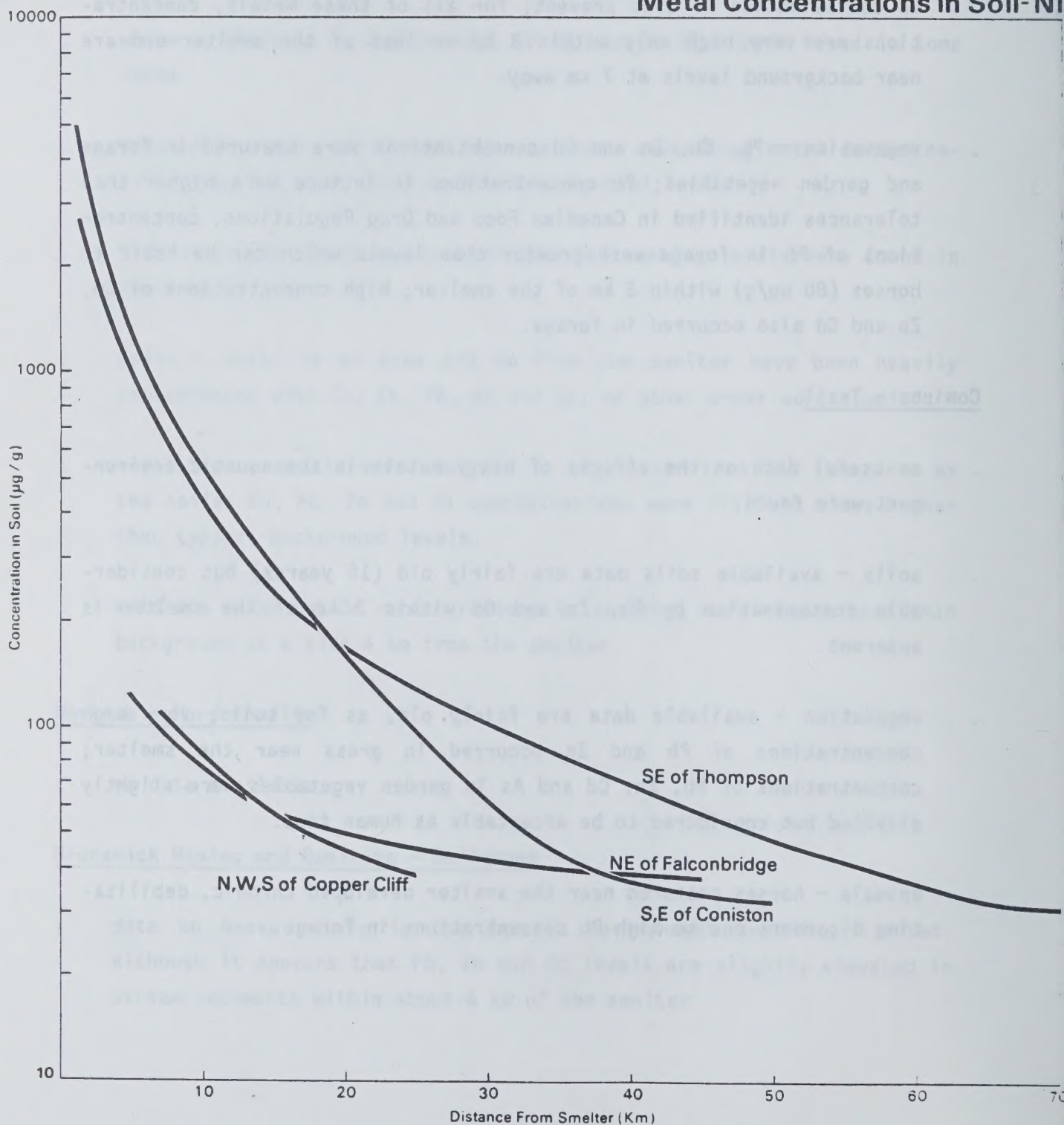


Figure 5.2.10-2

Metal Concentrations in Soil- Cu

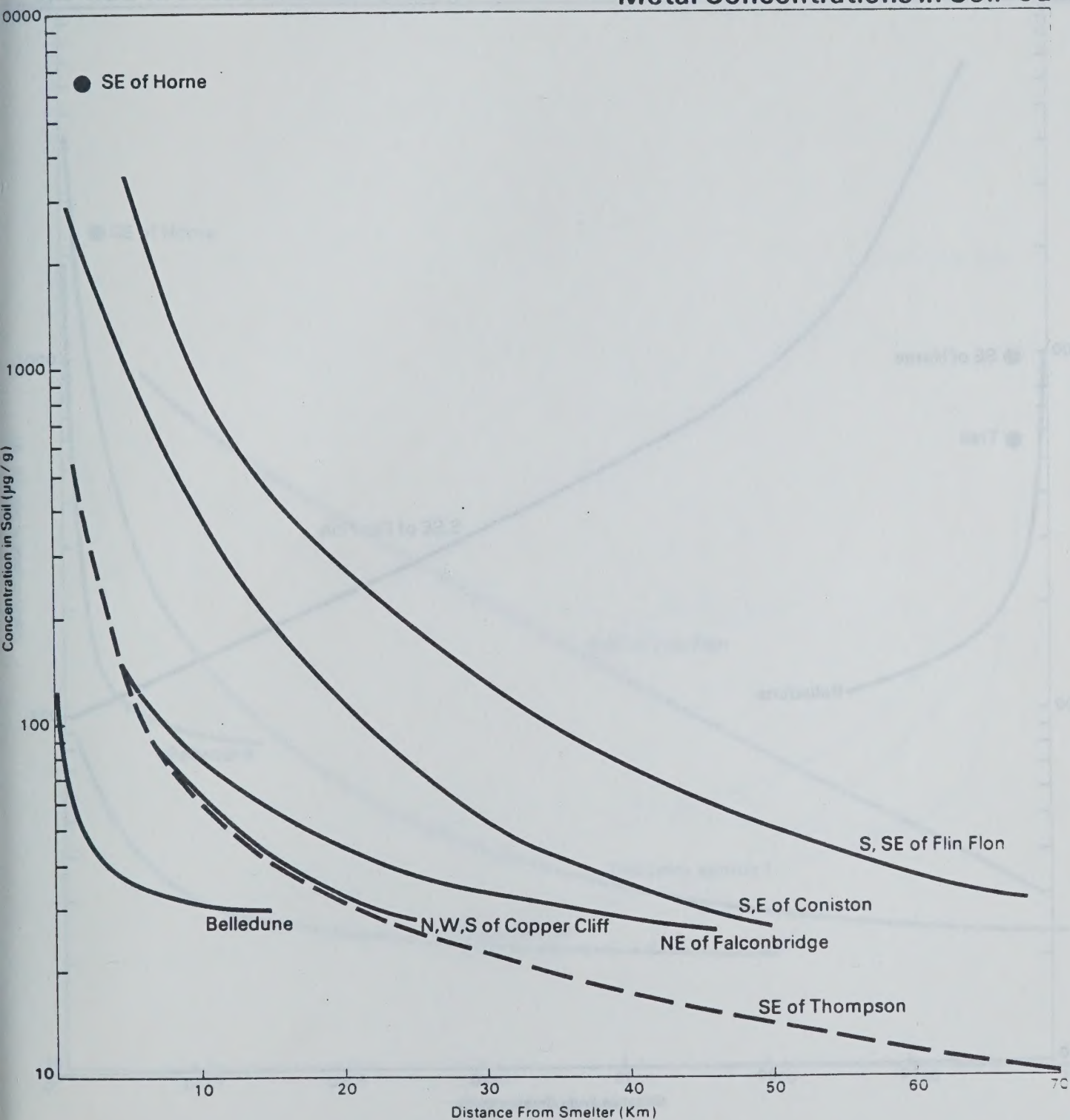


Figure 5.2.10-3

Metal Concentrations in Soil-Zn

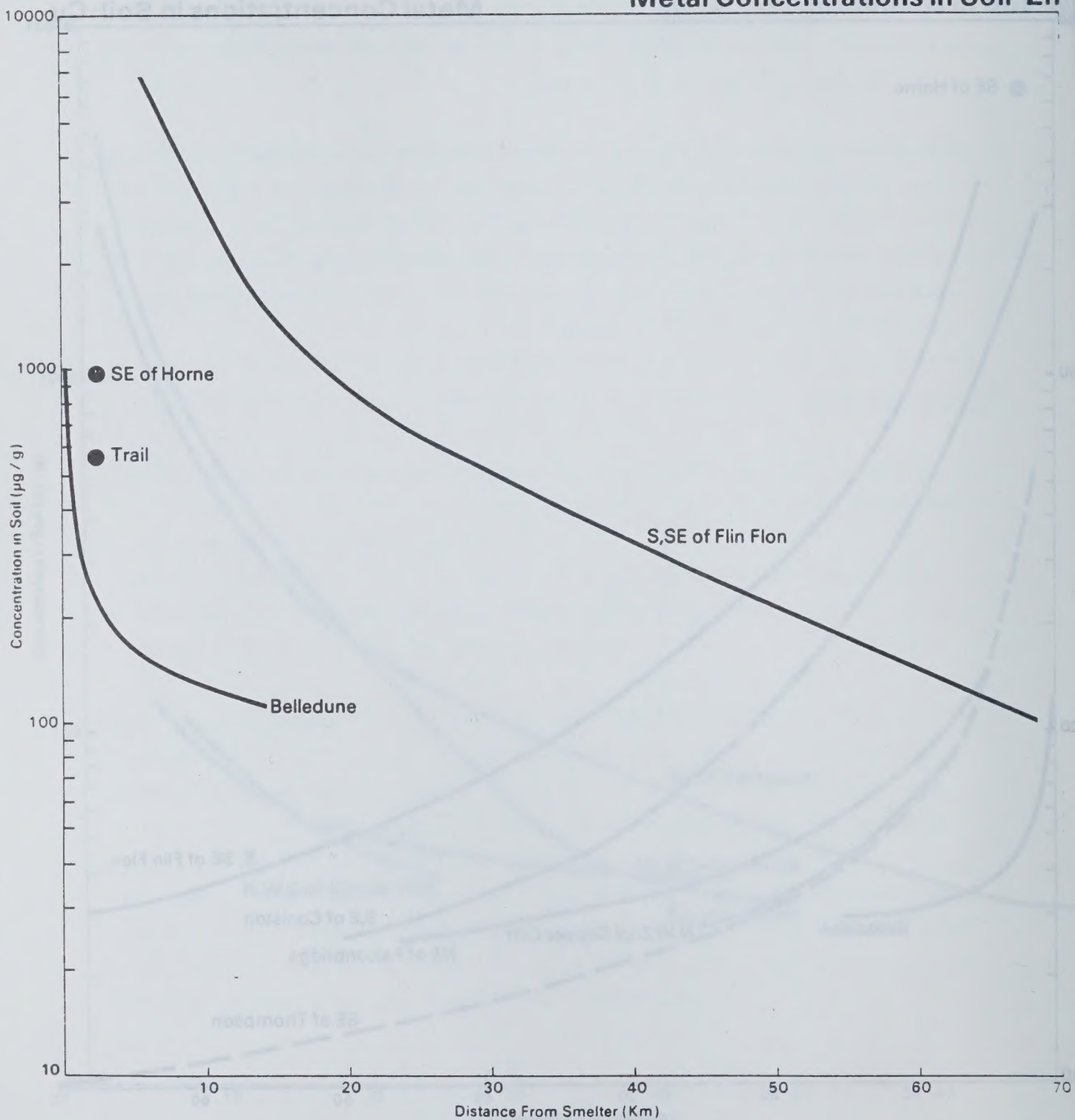


Figure 5.2.10-4

Metal Concentrations in Soil- Pb

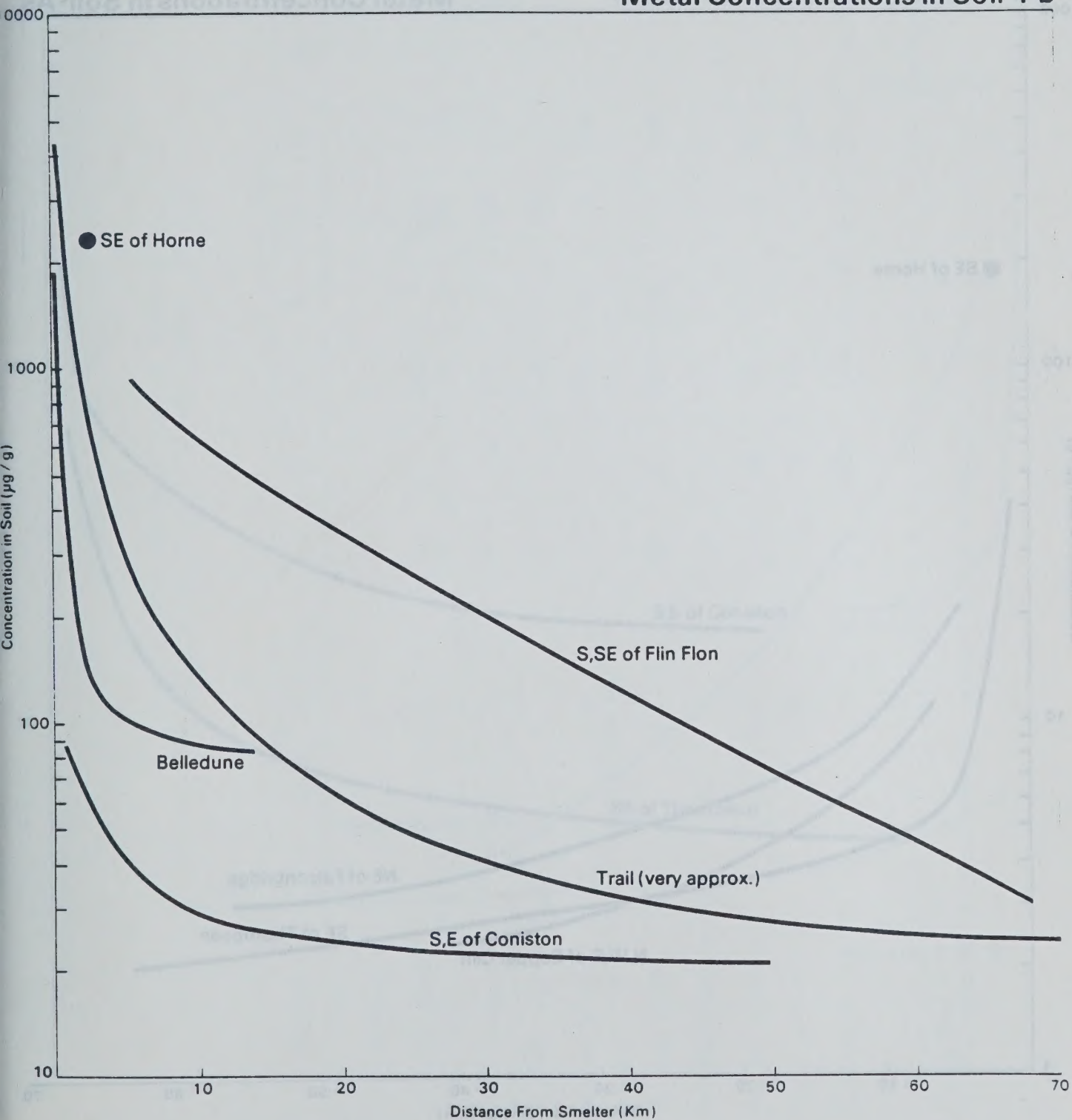


Figure 5.2.10-5

Metal Concentrations in Soil-As

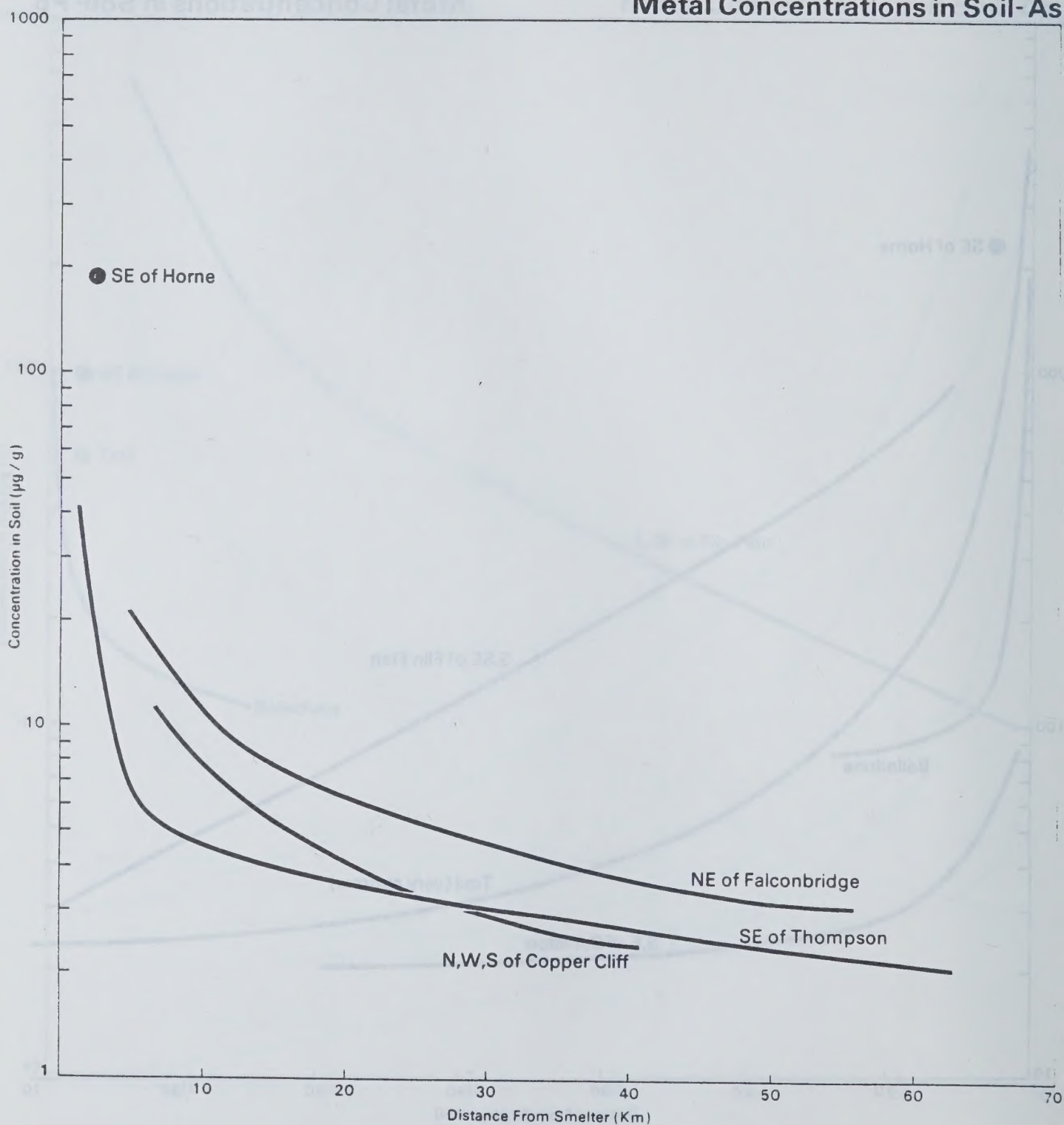


Figure 5.2.10-6
Metal Concentrations in Soil- Co

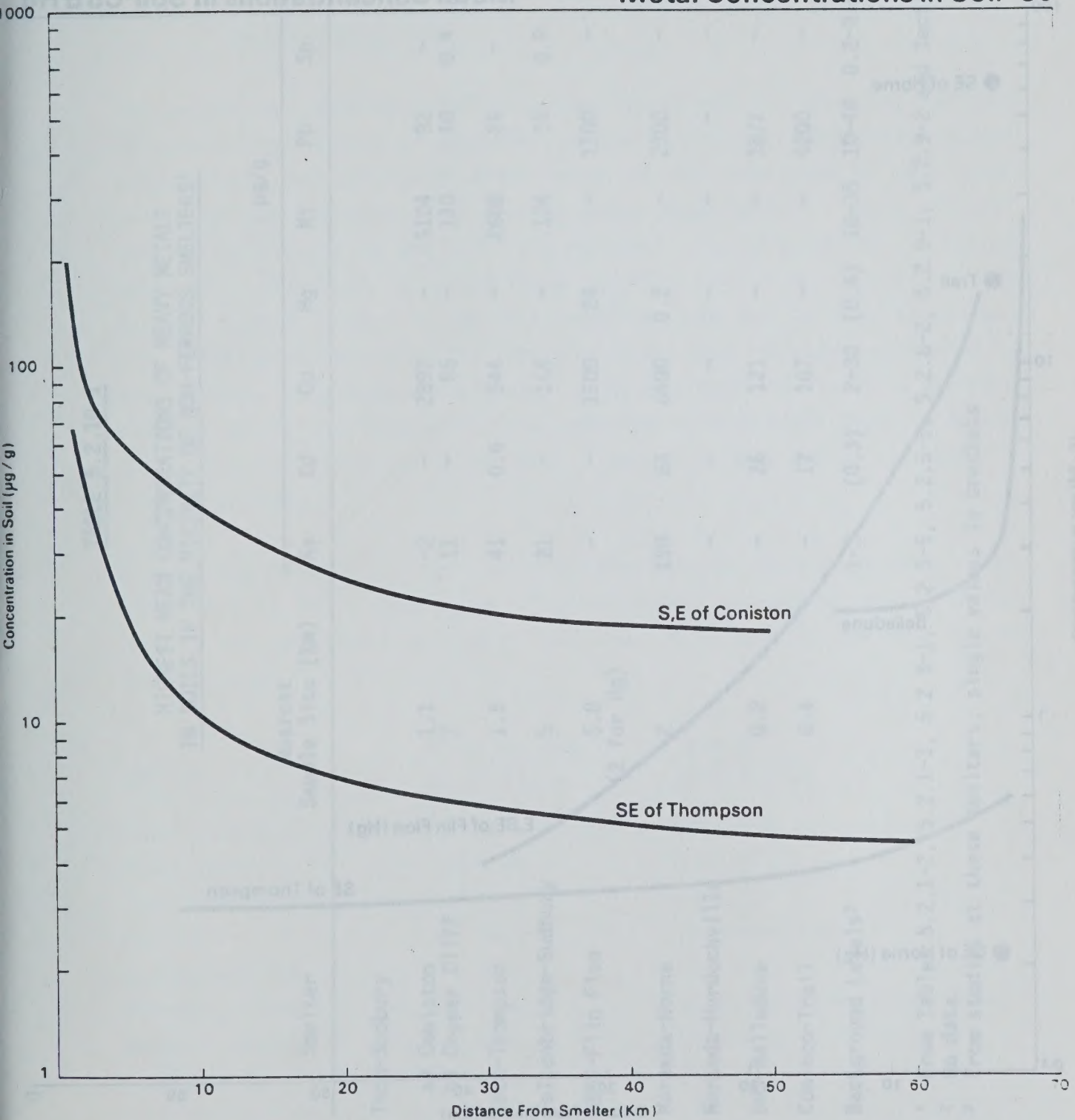


Figure 5.2.10-7

Metal Concentrations in Soil-Cd&Hg

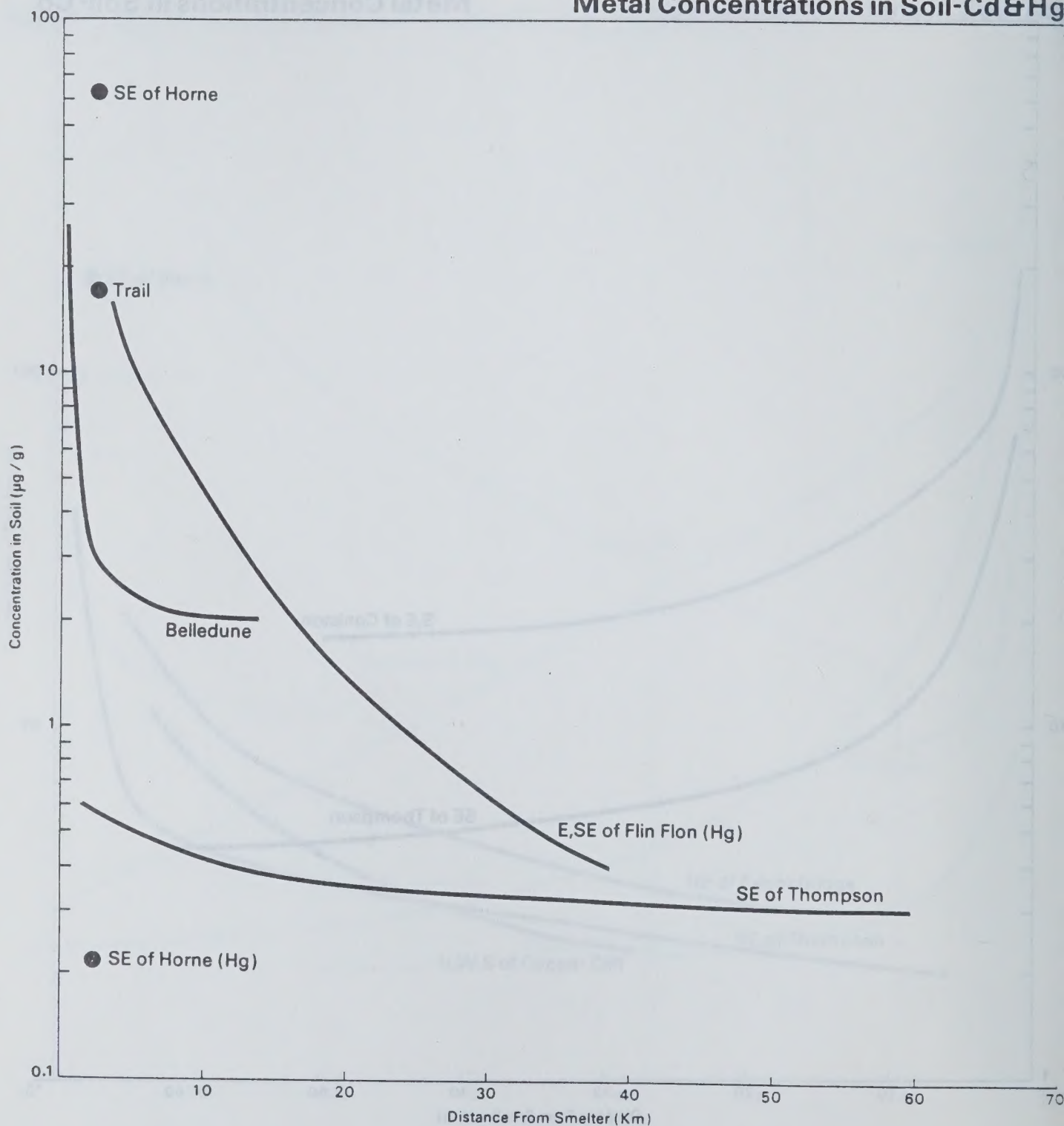


TABLE 5.2.10-1

HIGHEST MEAN CONCENTRATIONS OF HEAVY METALS
IN SOILS IN THE VICINITY OF NON-FERROUS SMELTERS¹

Smelter	Nearest Sample Site (km)	µg/g								
		As	Cd	Cu	Hg	Ni	Pb	Se	Zn	Co
Inco-Sudbury										
a) Coniston	1.1	-2	-	2892	-	5104	92	-	100	200
b) Copper Cliff	7	11	-	85	-	110	40	0.4	74	17
Inco-Thompson	1.5	41	0.6	544	-	2688	24	-	63	66
Falconbridge-Sudbury	5	21	-	144	-	124	35	0.8	67	12
HBMS-Flin Flon	5.8 (2 for Hg)	-	-	1500	24	-	1100	-	7400	-
Noranda-Horne	2	190	63	6400	0.2	-	2300	-	980	-
Noranda-Murdochville		-	-	-	-	-	-	-	-	-
BMS-Belledune	0.2	-	26	121	-	-	1872	-	987	-
Cominco-Trail	0.4	-	17	107	-	-	4200	-	571	-
Background Levels ³		1-3	(0.3)	2-30	(0.4)	10-35	10-40	0.2-0.5	15-100	3-30

¹ From Tables 5.2.1-2, 5.2.1-3, 5.2.3-1, 5.2.5-5, 5.2.5-6, 5.2.8-2, 5.2.9-1, 5.2.9-2 and Section 5.2.6.2

² No data

³ From studies at these smelters; single values in brackets

6.0 INFORMATION GAPS

6.1 Smelting Operations

The non-ferrous smelting community across Canada over the years has published various descriptions of operations including some environmentally related information. However, heavy metal emissions are considered by some to be sensitive and available only for in-house distribution. Part of this sensitivity relates to the difficult nature of producing reliable emission data and a reluctance to disseminate possibly inaccurate information. A further concern relates to possible responses from the surrounding community. Problems interpreting the impact of heavy metal emissions were discussed earlier. As a result, published, up-to-date stack and fugitive emission data are generally unavailable. The reference summary table shown in Appendix II illustrates the principal gaps. Lack of information on fugitives is a prime example.

Each of the smelters reviewed has a program intended to produce heavy metal emission data for a combination of metallurgical accounting, environmental impact, and government regulatory reasons. A summary of the most recent data follows:

<u>Smelter</u>	<u>Emission Data Date</u>	<u>General Completeness</u>
Inco - Sudbury	1981	Complete
Falconbridge	1980	Partial
Inco - Thompson	1980	Complete
HBM & S	1983	No Compositions
Cominco - Trail	1983	Partial
Noranda - Horne	1984	No Compositions except lead
Noranda - Gaspé	1983	Lead Only
Brunswick Smelting	1983	Partial

6.2 Heavy Metals Dispersion

The information gaps identified below for each of the smelters are those which are apparent from reviewing the literature. However, it is evident that additional data exists in unpublished form.

Inco and Falconbridge - Sudbury

Extensive air quality studies have been undertaken in the Sudbury area and as a result the effects of the two smelters have been fairly well described. Continuing monitoring programs (ambient air, deposition) will supplement the existing data base. However, there appears to be less minor impurity deposition data.

Inco - Thompson

There appear to be no data on heavy metals in ambient air in the vicinity of this smelter. The moss trap program appears to be capable of yielding good data but analysis should include other metals of concern (Pb, As, Co). Cobalt should also be included in snow analysis.

HBMS - Flin Flon

No data on heavy metals in ambient air were available. Arsenic and mercury should be included in the deposition studies (snow) since they have occurred at elevated levels in terrestrial and aquatic compartments.

Noranda - Horne

The ambient air information available for this study included virtually no heavy metal data. Extension of the snow sampling network would be required to determine to what distance significant deposition of Hg is occurring.

Noranda - Murdochville

No data were available for this study.

Brunswick Mining and Smelting - Belledune

No ambient air data were available for this study. Deposition rates were only available for lead; similar data are required for Zn, Cu, Cd and As.

Cominco - Trail

Air quality data for the Trail area which were reviewed during this study are somewhat dated and so may not reflect the current situation. However, more recent data will be available when the Phase II report on the Kootenay Air and Water Quality Study is released. The existing available information on deposition rates is dustfall data. Data on wet deposition or some measure of total deposition (eg. metals in snow) are required for a more complete understanding of the smelter's influence on deposition rates.

6.3 Human Health Effects

Limited human health related data was available for the Noranda (Horne) and Noranda (Murdochville) smelters. Information was not available for Inco (Sudbury), Inco (Thompson), Falconbridge (Sudbury), Hudson Bay Mining and Smelting (Flin Flon), Brunswick Mining and Smelting (Belledune) and Cominco (Trail).

While the Noranda (Horne) smelter had the most complete information, limitations to B.E.S.T.'s studies (Ref. Q1, Q3, Q4) include gaps in epidemiological data, restriction of emissions evaluated and lack of information on long range health effects. A follow-up epidemiological study on the respiratory functions of the Rouyn-Noranda population was recommended by B.E.S.T., based on SO₂ emissions. B.E.S.T. also recommended the implementation of a comprehensive air monitoring programme. Potential health effects of iron and copper emissions were not detailed in the reports. Biological testing was limited to lead, cadmium, arsenic and mercury. B.E.S.T. recommended follow-up lead testing in children. B.E.S.T. was unable to determine the long range effects of toxic materials on populations and communities surrounding Rouyn-Noranda.

The health related data concerning the Noranda (Murdochville) smelter, conducted by Laval University, was limited to a study of absorption of several heavy metals on Murdochville children, aged 2-12 years.

Only lead, arsenic and cadmium were tested in the population. Mercury, iron, copper and zinc emissions were not evaluated.

6.4 Other Environmental Effects

6.4.1 Inco - Sudbury

Aquatic Environment

The Sudbury area is the focus for considerable basic research into the effects of SO_2 and heavy metals on the aquatic environment, the mechanisms of these effects and means to counteract some of the effects (e.g. lake neutralization experiments). The effects of heavy metal emissions from Copper Cliff, as distinct from other nearby sources (i.e. Falconbridge), can only be examined indirectly, by modelling heavy metal deposition patterns from each major source.

No information was found concerning the accumulation of heavy metals in fish in the Sudbury area. Although fish have often been eliminated from lakes by acidification in those areas where heavy metal deposition is high, data on surviving fish populations would be useful with regard to human consumption considerations.

There are no data on Co and As in the aquatic environment, although these are present at elevated concentrations in terrestrial compartments.

No information was found on the effects of heavy metals on wildlife which feed on aquatic biota (e.g. muskrat, otter, ducks, etc.).

Terrestrial Environment

No information was found concerning the effects of heavy metals on soils and vegetation close to the smelter (within 7 km). Effects of heavy metal emissions on wildlife in the Sudbury area have received little study. Data on heavy metal concentrations in garden vegetables should be acquired.

6.4.2 Inco - Thompson

Aquatic Environment

Essentially no useful data were found concerning the effects of atmospheric heavy metal emissions on the aquatic environment in the Thompson area.

Terrestrial Environment

Good data were available concerning effects on soils and vegetation, although metal concentrations in garden vegetables are required. However, with respect to wildlife, some data suggested that population densities of some small mammal species may be affected by heavy metals in the environment. A thorough trapping program in areas of comparable habitat, but with different levels of contamination, would help to clarify this situation.

6.4.3 Falconbridge - Sudbury

Aquatic Environment

As indicated in Section 6.3.1 (Copper Cliff), the effects of heavy metal emissions from the Falconbridge and Copper Cliff smelters on the aquatic environment cannot be readily separated, although for the Sudbury region, in general, Copper Cliff's emissions are considerably more important. Also, there is much research being carried out in the Sudbury area on the aquatic effects of heavy metals and acid precipitation. It is therefore considered that there are no distinct data gaps specifically with respect to the Falconbridge smelter. However, as noted in Section 6.3.1, there is no information on the effects of heavy metals on aquatic wildlife (muskrat, etc.) and analyses of heavy metals in fish would be desirable.

Terrestrial Environment

No information was found describing effects of heavy metals on soils and vegetation close to the smelter, including concentrations in these media and toxicity of the soil to seed germination and plant growth. Concentrations of heavy metals in garden vegetables should also be determined. There is very little information on wildlife effects in the Sudbury area.

6.4.4 Hudson Bay Mining and Smelting - Flin Flon

Aquatic Environment

Laboratory studies or a literature review on the influence of Ca concentration on heavy metal uptake by aquatic macrophytes and fish would be useful in evaluating the effects of heavy metal emissions on aquatic biota in the Flin Flon area.

Adequate data to describe the effects of heavy metals on plankton and aquatic invertebrates are lacking.

Since heavy metals have adversely affected spawning of white suckers in Hamell Lake, reproduction of other species and in other nearby lakes should be investigated. Fish studies in the Flin Flon area should include measurements of Zn, Pb, Cd, Cu, Hg and As in flesh. Concentrations of As, Pb and Hg in water are also required.

Terrestrial Environment

It was suggested that red-backed vole abundance has been reduced near the smelter due to heavy metal emissions (Ref. M17). An intensive trapping program would be required to confirm this.

Since high concentrations of Hg and Pb have been found in blueberries near Flin Flon, other plant materials grown locally for human consumption should also be analyzed.

There are no data on concentrations of Cd and As in soils.

6.4.5 Noranda - Horne

Aquatic Environment

Although data are available on heavy metal concentrations in surface waters and sediments, the number of sampling locations (receiving metal contamination only by atmospheric deposition) was too small to obtain a good regional appreciation of the influence of smelter emissions. More extensive examination of heavy metals in fish is also desirable, particularly with respect to mercury.

No data were available on accumulations of heavy metals in plankton, aquatic macrophytes or aquatic wildlife.

Terrestrial Environment

The concentrations of heavy metals in soils and vegetation have only been determined within a small area 2-3 km south-east of the smelter. The high metal concentrations found in this area suggest that significant soil contamination could exist over a large area. This can only be investigated by a fairly extensive soil analysis program. Concentrations in vegetation, particularly species eaten by humans or domestic animals should also be determined over a broad area.

Toxicity of the soil in different areas to the growth of tree seedlings should be investigated to provide data for any future revegetation programs.

Little information is available on effects of heavy metals on wildlife in the vicinity of the smelter.

6.4.6 Noranda - Murdochville

There appears to be a total absence of publicly-available environmental effects information for the Murdochville smelter and the nature of any programs carried out in-house by Noranda is unknown.

6.4.7 Brunswick Mining and Smelting - Belledune

The studies on the environmental effects of atmospheric heavy metal emissions have so far concentrated on Pb, Zn and Cd, and, to a lesser extent, Cu. However, as As emissions are predicted by Hatch Associates (1981), both aquatic and terrestrial programs should include some analyses of As at sites close to the smelter to determine whether or not any accumulation is occurring.

Aquatic Environment

The available data are insufficient to identify what effects smelter emissions are having on fresh-water environments in the Belledune area. Accumulations of heavy metals are best detected in lakes, however these are uncommon and very small in this part of New Brunswick. Aquatic studies should therefore continue to focus on streams, which are numerous and support most of the local angling activity (brook trout, salmon). The following work is considered necessary to evaluate smelter impacts:

- surface water quality, including Pb, Zn, Cd, Cu, As, in upstream, downstream and possibly middle reaches of watercourses within about 20 km of Belledune.

heavy metals (Pb, Zn, Cd, Cu, As) in stream sediments with sampling locations as for water quality; because of the variability of stream sediments, several samples should be collected from the vicinity of each location.

Studies on fish and other biota should be deferred unless it is demonstrated that significant contamination of stream water or sediment has occurred.

Terrestrial Environment

Good data are available on the concentrations of heavy metals in soils and crops, however, some As analyses should be made. In view of the high concentrations of metals in soil within 1 km of the smelter, studies of crop growth on these soils would be valuable. The high concentrations of Pb in forage is a concern with respect to toxic effects on domestic animals (especially horse) and wildlife. Possible effects on domestic animals can be determined by veterinary examination of animals pastured close to the smelter, including analysis of Pb in blood samples. Small mammals should be captured at various distances and analyzed for heavy metal content; physical measurements should also be recorded.

6.4.8 Cominco - Trail

Aquatic Environment

No information has been received concerning the effects of atmospheric heavy metal depositions on the aquatic environment.

Examination of metal contamination in surface waters in the Trail area should include sampling of water and sediments in nearby headwater streams and lakes. Assessment of effects would be greatly enhanced by analysis of snow and soil samples near the streams and analysis of stream water during

snowmelt. Some watercourses in this area receive metal contamination from effluent discharges and runoff from mine sites; these water quality impacts should be identified and distinguished from the effects of atmospheric deposition.

Terrestrial Environment

The data which have been received on concentrations of heavy metals in soils and vegetation are in the order of 15 years old. More recent data are required to assess environmental effects, particularly with respect to Pb. Also no information on effects of heavy metals on wildlife or on toxicity to plant growth have been seen.

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Appendix I

Reference Cross-Check Table

APPENDIX I
HEAVY METALS KEY REPORTS CROSS-CHECK LIST

HEAVY METALS KEY REPORTS CROSS-CHECK LIST														
OPERATION	OVERVIEW PLANT DESCRIPTION	OPERATION PRACTICES CONDITIONS	CLIMATIC SETTING	POLLUTION ABATEMENT EQUIPMENT	STACK EMISSIONS	FUGITIVES & SAMPLING PROGRAMS	LOCAL DEPOSITION AND ENVIRONMENTAL EFFECT						OTHER REPORTS	
							AIR	WATER	SOIL	ANIMAL	HUMAN	VEGETATION		OTHER
FALCONBRIDGE	01, 027, 029	027, 038,	032, 632, 633 631,	027, 029,	69, 01, 014 015, 017, 030	01, 05, 028 043, 051	03, 07, 010 033, 045,	018, 019, 033 048,	021, 021, 023 032, 033, 046	031,	020, 021, 033 034, 040,	07, 08, 015 017, 022,	02, 04, 06 09, 011, 012, 036, 037, 051, 053, 054, 056, 059,	
INCO-SUDBURY	01, 041, 049 038	039, 040, 037	032, 631, 632 633,	040, 041,	69, 01, 013 014, 016, 017 030, 038,	01, 042, 044	03, 07, 010 033, 045, 060	018, 019, 026 033, 048, 052 060, 061, 062 063,	020, 021, 023 024, 025, 032 033, 046, 047 060	031,	020, 021, 033 034, 038, 046 058, 060,	07, 08, 015 017, 022, 055 060,		
INCO-THOMPSON	M13	M13,	631, 632, 633	M13,	M7, M14,	M20,	M14, M19,		M7, M14, M19	M14,	M7, M14, M19	M7, M19,		
MMI & S	67, M2, M3, M18	M3,	631, 632, 633	67,	67, 68, 69 M3, M5, M18	M1, M2, M21	M9, M10, M11 M12, M16, M22 M28, M29, M30		M4, M6, M25 M26, M27,	M6, M9, M10 M11, M16, M17 M30,	M4, M6, M24 M25, M26, M27 M28,	M4, M6, M12, M15 M16, M23, M27 M28,	M8,	
CORINCO TRAIL	67, 68, 69 B11,	612, 68,	631, 632, 633 612,	67, 69, 810 812, 68, 813, 816, 817	67, 69, 81 82, 84, 810 811, 823, 812	64, 85, 86 89, 813, 814 913, 816, 817	818,	812, 818,	818, 819, 820 822,	818, 819,	818, 819, 821 822,	818,		
BM & S	67, M1,	M6,	631, 632, 633	67, M6,	67, 68, 69 M1, M3, M5,	M4, M7,	M3, M6, M9,	M3, M6, M9,	M2, M3, M6, M8, M9,	M6,	M6, M8,			
NORANDA-HORNE	68, 012, 018 019,	018, 019	631, 632, 633	68, 019, 018	69, 06, 08, 014, 022	016, 022,	04, 05, 08 09, 010, 013	04, 05, 09, 010, 013,	04, 05, 09, 010, 013,	04, 05, 09, 010, 013,	01, 02, 03, 04, 05, 09, 010, 013,	04, 05, 09, 010, 013, 057	08, 013, 07, 015, 017, 021,	
NORANDA-GASPE	012, 020,	012,	631, 632, 633	012,	011, 014,	016, 022,				020,				
OTHER	67,				67,		98, 83,	810,	024, 032, 046 57, 59,	52,	51, 52, 53, 54,	046, 057, 58, 57, 59, 510	55,	
SHELTERS														
EFA REPORTS	E2, E3, E6, E7,			E4,	E2, E3, E6, E7,	E1, E2, E3, E7,	E2, E3, E7, E7,		E8, E9, E10	E9, E10		E8, E9, E10	E5,	
GENERAL				65, 015	627, 628, 629 627,		611, 617, 614 613, 620, 627 629,	03, 04, 012 013, 014, 015 019, 020, 023 024, 026, 027	67, 64, 613 614, 615, 616 618, 620, 623	67, 64, 613 614, 615, 619 617, 618, 619 619, 621, 622 620, 621, 620 622, 631, 636	67, 64, 616 617, 618, 619 619, 621, 622 620, 621, 620 622, 631, 636	61, 62, 674 64, 66, 613 614, 615, 619 619, 621, 622 620, 621, 620 622, 631, 636	627, 628, 629 627,	627, 628, 629

Appendix, II

Smelter Flowsheets

OPERATIONS
FLOWSHEET

OPERATIONS FLOWSHEET

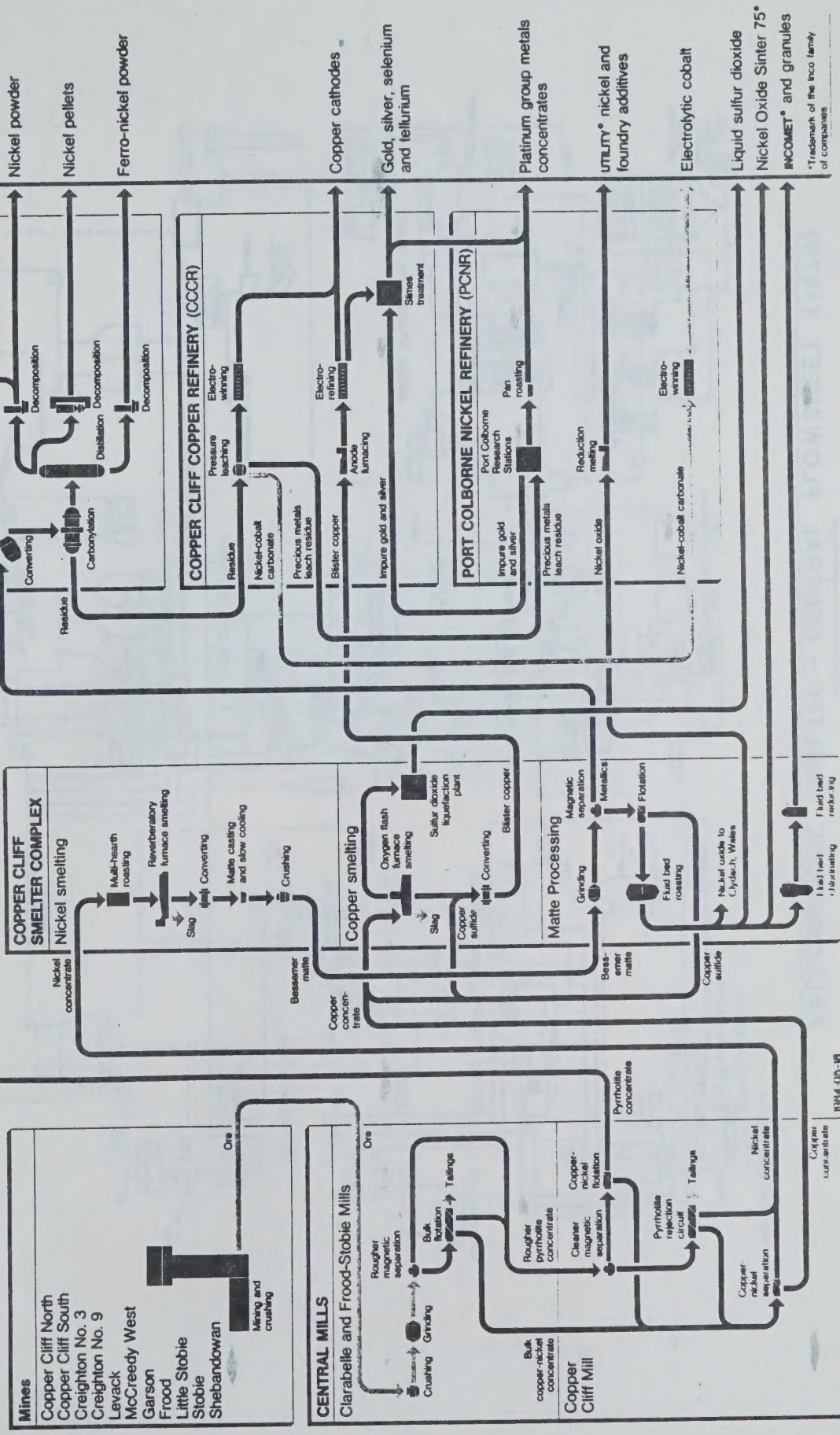
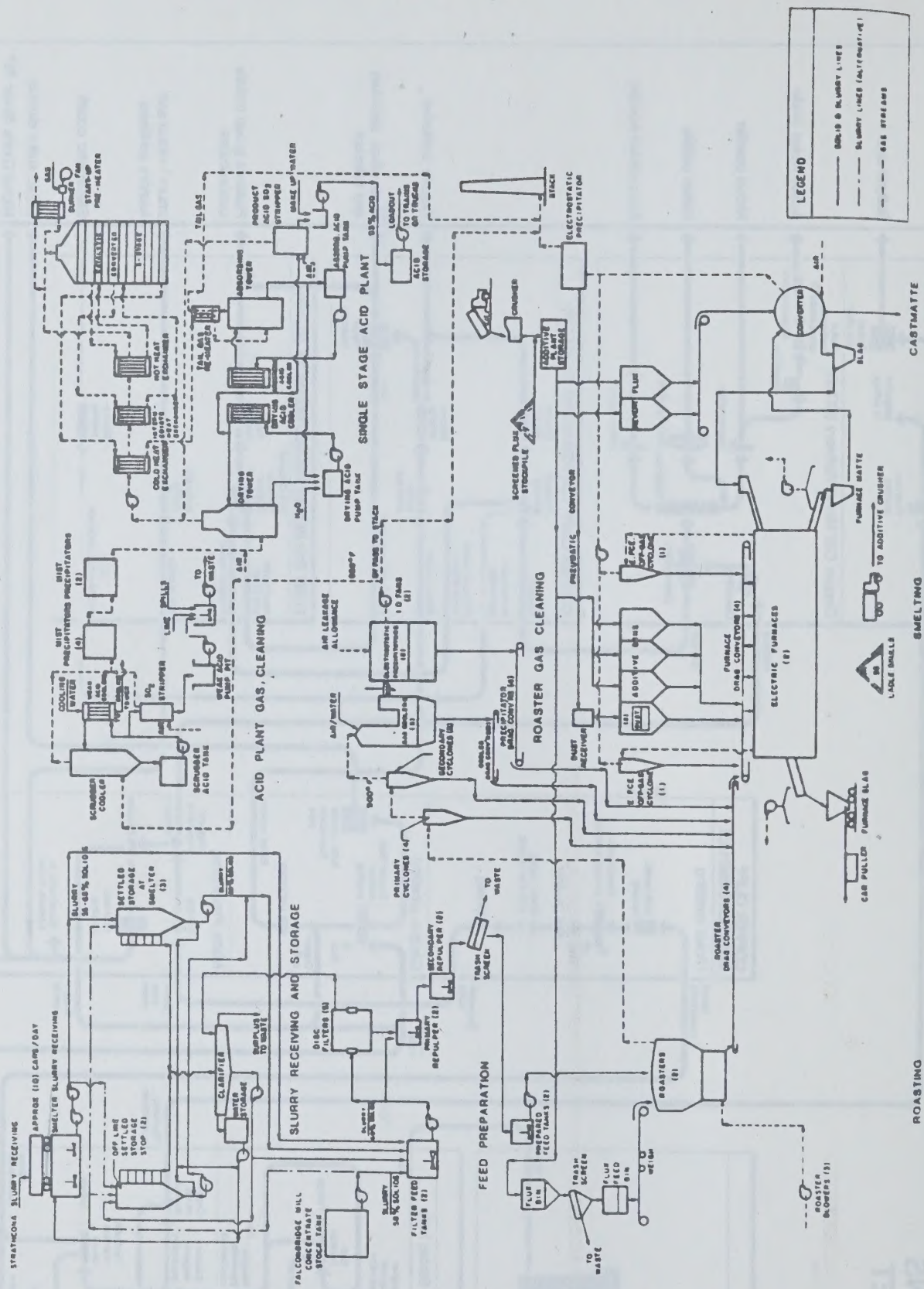


FIGURE AII-2

FALCONBRIDGE SMELTER - GENERAL FLOWSHEET (1979)



R0689 ENVIRONMENTAL MANAGEMENT - ESE 1008S 3-D
Investigation of Environmental Effects of Heavy
Emissions from non-Ferrous Smelters. / FENCO
Inc. 1985.

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